Resource assessment of deciduous forests in Bangladesh

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ABSTRACT

This research makes a new assessment of both the physical and social dimensions of deciduous forest resources located in the central part of Bangladesh. Satellite remote sensing data and techniques are used to detect spatial and temporal forest change, to measure forest biophysical variables and to appraise their potential for developing model predictions based on a field survey conducted in 2003. Post classification assessment and regression analysis were the main methods in remote sensing data analysis. The study focused on a part of deciduous forest (64 sq km) located in Madhupur thana for fine-scale forest assessment. Remote sensing results suggest that only 16 percent forest left in the study area compared to 3826 hectares in 1962. The forest biophysical variables show strong association with spectral information of satellite data. For instance, an R-squared of 0.79 for predicted variable (for tree height) was achieved while regressing with field data, indicating that remote sensing methods can be efficiently used even in the tropical forests where heterogeneity is common.

The second part of the thesis focuses on the underlying social factors/drivers that impacted on the forest, ranging from social dynamics such as land tenancy disputes, historical legacies and local corruption to policy failure by employing the theoretical framework of political ecology. Political ecological analysis in this research helped to evaluate the role and inter-relations of power, the ideological dilemmas and methodological disputes (i.e. the way forest problems are perceived) over forest resources in the study area. Field survey and observation was also found useful in gathering information about social variables by interviewing local inhabitants, forest officials, NGO activists, and politicians. The research employs methodologies from both science (i.e. remote sensing) and social science (i.e. political ecology) and the findings suggest that these two strands can work together for the better management (including resource assessment, monitoring and progress evaluation) of resources in Bangladesh.

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Glossary

Abbreviations, symbols and terminologies are defined where they are introduced. Some of the commonly used terms/symbols are described in the following,

Variable name	**Description**
dbh (diameter at brest height)	Tree diameter at 1.3 m above ground level.
Basal area (g)	The cross-sectional area of all (living) trees in a compartment measured at 1.3 m above ground height, expressed in m2/ha.
Tree height	Arithmetic average height of all living trees in the stand (m).
Tree density	Number of trees per hectare (trees/ha).
Wood volume (V)	Forest stem volume (m^3/ha)
R^2	Multiple coefficient of variation
r (correlation coefficient,)	The correlation coefficient is (and is only) a measure of linear association between variables.
RMSE	The square root of the mean square error
Kappa (K)	Statistical value that demonstrates the level of accuracy of image classification results
BTM Projection	Bangladesh Transverse Mercator Projection
ETM+	Landsat 7 Enhanced Thematic Mapper Plus
TM	Thematic Mapper sensor onboard Landsat 4 and 5 satellites.
MSS	Multisepctral sensor onboard Landsat 1, 2 and 3 satellites.
LISS-III	Indian Remote Sensing Satellite (Linear Imaging Self Scanning Sensor.
KH4	Designation of Corona satellite system of United States.
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
GPS	Global Positioning System
GCP	Ground Control Points

List of Abbreviations

ADB	Asian Development Bank
BARC	Bangladesh Agricultural Research Council
BBS	Bangladesh Bureau of Statistics
BCAS	Bangladesh Centre for Advanced Studies
BFD	Bangladesh Forest Department
BFRI	Bangladesh Forest research Institute
EBSATA	East Bengal State Acquisition and Tenancy Act
FAO	Food and Agricultural Organisation
FSP	Forestry Sector Project
GEO	Group of Earth Observation
GEOSS	Group of Earth Observation System of Systems
GPS	Global Positioning System
IGOS	Integrated Global Observing Strategy
IFOV	Instantaneous Field of View
IPCC	Intergovernmental Panel on Climate Change
IUCN	The World Conservation Union
JRC	Joint Research Centre
PRSP	Poverty Reduction Strategic Plan
MoEF	Ministry of Environment and Forest
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NFI	National Forest Inventory
NRC	National Research Council
TREES project	Trans-Agency Resources for Environmental and Economic Sustainability
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNICEF	United Nations International Children's Emergency Fund
USAID	United States Agency for International Development
Thana	Fourth level administrative unit of Bangladesh.

Appendices

Declaration of Copyright

Signed,

Date:

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This thesis is a significant product of my life and has enriched me in various different ways. I can now feel the difference (in terms of maturity) between myself now and myself before the commencement of the work. It also taught me the tactics of making a balance between the tedious, long research works other important things in life. It would not have been completed without the support of my sponsoring agency, the British Commonwealth Commission. I wish to express my sincere thanks for their financial assistance and overall guidance that has made my life easy in the UK during the last three and half years.

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Chapter 1
Introduction

1.1. Introduction

Three distinct natural forest types are found in Bangladesh: evergreen hill forests, deciduous sal forests and mangrove forests. According to the official statistics, the sal forests in the central parts of the country are said to occupy one hundred twenty thousand hectares (BBS, 2002) of land where the sal (*Shorea robusta*) tree is the predominant species. The sal tree generally grows up from coppice origin on iron-enriched reddish soil formations. This deciduous forest type has been exploited by selective, clear felling of trees, by the transformation of forest lands into growth centres, security installations (Farooque 1997), for settlement and agricultural purposes, and by the consequences of government planning policies. Many authors mentioned population pressure as the prime cause of deforestation in Bangladesh including in the study area (FMP 1993, Gani 1990, Mahtab and Karim 1992). Based on the population pressure assumption many interventions from different sectors including public, donors and NGOs have taken place in the study area with the explicit aim of resource enhancement. Social forestry (also called participatory forestry) is one of such prescribed programmes recommended (Task Force Report 1987, GoB 1992, FMP 1993) and implemented in the area. Many authors / donors (Bhuiyan 1994, ADB 2001) supported this approach and advised for the improvement of social forestry. But the main problems like historical legacies, inappropriate policies (e.g. forest policies, population and migration policies, land use and land taxation policies etc.), vested interest of certain groups, land tenurial disputes, inefficiency and massive corruption of government officials, lack of accurate information on forest resources are not addressed in research studies.

Accurate and up-to-date information on forest condition, distribution and nature of forest change may help researchers/policy planners to develop better forest management plans. On the other hand, effective management of forest resources requires a clear understanding of the social factors that affect human-nature interaction in tropical forest environments and sometimes undermine the limits of natural resources to support human needs. Traditionally the state has operated a top-down approach of *environmental management*[1] that rarely grasps the root causes of problems and, rather, deploys projects and enforces laws, policies and regulations in the hope of restoring the environmental wellbeing. It is rare for the interests and approaches of environmental managers and the local people to be mutually agreed. Lack of agreement between managers and the local population can cause mistrust, violence and the emergence of grassroots movements that lead to still further deterioration of forest natural resources.

This study therefore attempts to integrate methods of human and physical geography (e.g. remote sensing and political ecology) to better understand the problem so that the changing pattern of forest resources can be ascertained and questions of why, how and by whom that change happened can be addressed. The established methods of satellite remote sensing (from physical geography) have been used to describe the pattern of forest cover change and assess its current condition; political ecology (from human

[1] The concept of *environmental management* is strongly criticized by many scholars (Blaikie and Brookfield 1987, Redclift 1994, Johnston 1996) for being *technocratic*, and not viewing environmental problems within wider political, economic and social contexts (Bryant and Wilson 1998).

geography) has been employed to help understand the underlying cause (social factors and policy problems) of deforestation. It is hoped that creating a wider picture of the problem considering its multi-dimensionalities may help the process of forest management planning to help protect the remaining resource. This is a challenge since assessing problems using an integrated science-social science approach is rare even within the domain of geographical research. However, both the components (remote sensing and political ecology) are presented as simply as possible so that the reader can get the message without the need for an in-depth knowledge of either approach.

First, a brief discussion is given in the following sections on global forest resources followed by South Asian and Bangladesh forests before setting out the aims and objectives of the research.

1.2. World Forest Resources

Forests are, at present, of great importance in the world for various reasons. These reasons may be divided into local and global concerns. Local concerns comprise loss of timber and non-timber resources to support local communities and their livelihoods, impacts of deforestation on ecosystem-functions and habitats. On the other hand, carbon storage, climate change / global warming, loss of biodiversity are regarded as major issues of global significance. These concerns contribute to the change in the methods that deployed to develop forest estimates reflecting the changing nature of demand of information (Mather *et* al. 2005). For instance, earlier forest estimates (i.e. Zon and

Sparhawk 1923, FAO 1937/46, FAO 1963, cited in Mather *et* al. 2005, see table 1) are quite different from recent global forest estimates (i.e. FAO 1995, FAO 2000, FAO 2005, see www.fao.org/) in terms of their aims and purposes (e.g. the particular emphasis on the measurement or estimation), definitions and forest variable categories.

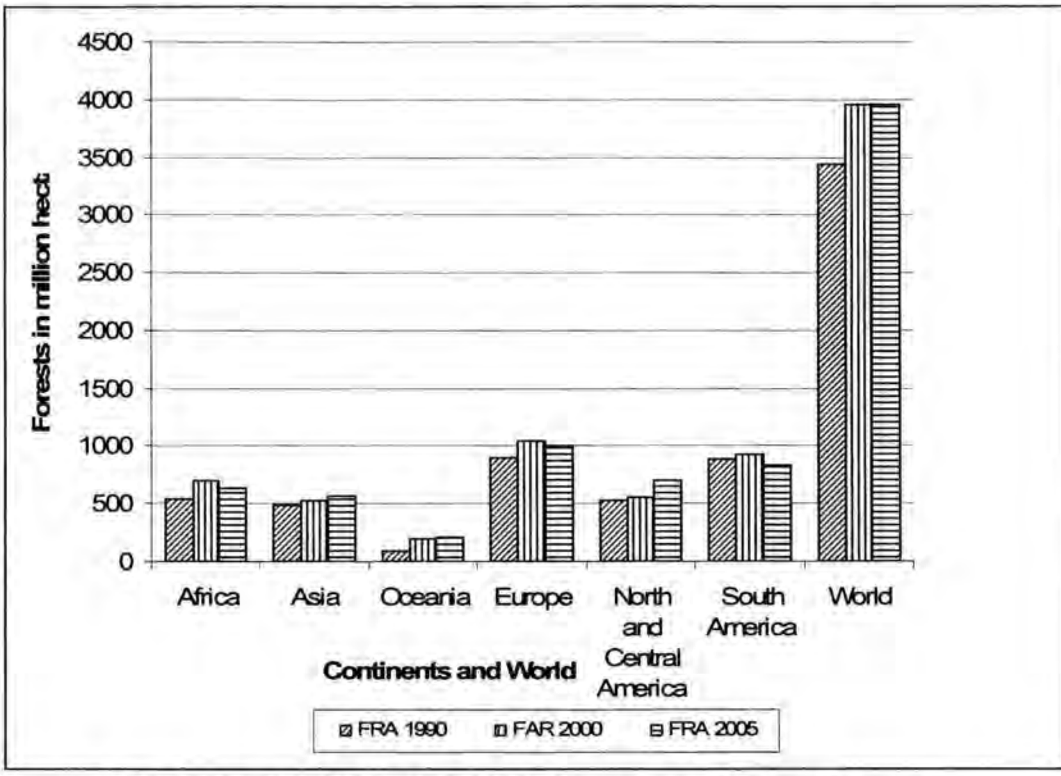
Table 1: World forests in different assessments.

Sources	**Date**	**Category**	**Area (million ha)**
Zon and Sparhawk	1923	Forest	3031
FAO	1937/46	Forest	3650
FAO	1963	Forest	3779
FAO	1990 (1995)	Forest	3442
FAO	2000	Forest	3869
FAO	2005	Forest	3952

Source: Modified after Mather *et* al. 2005.

At present, Food and Agricultural Organization of the United Nations (FAO) play a key role in estimating global forest cover although other projects, like EC's TREES project, IUCN's atlas of tropical forests and NASA'a Landsat Pathfinder project also contribute to develop global forest estimates/maps. According to the 2005 FAO Forest Resources Assessment (FRA, 2005, see www.fao.org/), global forest cover is estimated just below four billion hectares or 30% of the total land area of the world. This corresponds to an average of 0.62 ha of forest per capita (FAO 2005). FRA 2005 further mentioned that forestry is unevenly distributed throughout the world. Most forestry is concentrated in Europe and that accounts for about one billion hectares (figure 1). The second largest concentration exists in North and Central America (705 million hectares in FRA 2005 estimates), where Africa and Asia account for 637 and 571 million respectively. South and South East Asian countries hold most of the forest concentrations for Asia.

Figure 1: Comparison of global forest estimates.



Source: FAO 1990, FAO 2000, FAO 2005. Source: www.fao.org/forestry.

World forests are classified in different categories on the basis of climatic conditions such as tropical, boreal, tundra, savannah forests. Tropical forests are most diverse, most ecologically complex of land communities (Myers 1984) and most disturbed by human impacts. Tropical forests contain some of the oldest and richest ecosystems (Laurance 1999), containing more than fifty percent of all species of plants (Poore 1991). Poore (1991) mentioned that with existing knowledge about 15,000 different plants support some kinds of non-timber use. This forest is also home to many of the world's indigenous cultures. About 50 million indigenous people live in tropical forests alone (WRI 1997, see www.wri.org/). The area of the tropical rain forests forms a belt around the whole earth. Richards (1996) mentioned that the tropical rain forest formation-type comprise three floristically different formations occupying the main regions of the world with a humid tropical climate: (i) the American rain forest in the South and Central America, (ii) the African rain forest in tropical Africa, (iii) the Indo-Malayan rain forest, which is found from India to Southern China and New Guinea, (iv) a fourth formation, smaller than the others, is found North Eastern Australia. Despite differences in species, families and genera, the structure, physiognomy, successional stages in their development, tropical rain forests are alike in many respects (Richards 1996).

Many authors critically examined FAO global forest assessments and showed their concerns about the quality, completeness and methodologies. Mather *et* al. (2005) stated that FAO global forest estimates are flawed and failed to yield time series data relating to the global forest, even for the attributes such as area. Abnormal differences in forest area statistics are also apparent from successive FAO state-level. For example, the FAO assessment of 2000 indicated that the forest area in Australia is 155 million hectares, compared with 40 million in the 1990. For Angola, the corresponding figures were 70 and 23 million hectares. World Resources Institute (WRI 1997) also disagreed with FAO forest estimations. WRI (1997) defined (on the basis of seven criteria) world tropical forests, in their term 'Frontier Forests' (figure 2), as the large, ecologically intact and relatively undisturbed natural forests that still remain.

The Original Forest (forests that covered the planet 8000 years ago)

The Current Forest (based on current available information)

The WRI's Frontier Forest (remnants of original forest)

Source: World Resources Institute (www.wri.org) 2006. Accessed on 14th August 2005.

Note: The map on the top is prepared by World Conservation Monitoring Centre (WCMC) on request from WRI as termed as 'Original Forest' of the world. The 'original forest estimated to have covered the planet about 8000 years ago, before large-scale disturbance by modern society began'. Bottom two maps are prepared by WRI on the basis of available information. WRI termed *Frontier Forests* as the world's remaining large intact natural forest ecosystems based on seven criteria (WRI 1997).

Figure 2: World forests in different phases.

WRI claimed that only 40% of the FAO estimated current world forests (i.e. 1.5 billon hectares out of 3.9 billion hectares of global total) can qualify as frontier forests and 39% of that 1.5 billion hectares of frontier forests are now threatened by logging, agricultural clearing, and other human activities. In collating global forest estimations, FAO gathered information from (i) existing forest inventories, (ii) regional investigations of land cover change, (iii) a number of global studies focusing on the interaction between people and forests (FAO 2005). The FAO estimates show general agreement with other pan-tropical forest inventories like EC's TREES project, IUCN's atlas of tropical forests and NASA's Landsat Pathfinder project. But when compared with country level assessments, then disagreements arise (Mayaux 1998). Mayaux suggested that discrepancies are most like to be due to happened due to forest definition differences among the agencies, differences in data source and processing methodology.

1.2.1. Forests in South and South East Asia

It is mentioned earlier that South and Southeast Asia contains most of the forest cover for Asia, where Indonesia holds the most (Table 2) forest cover. Most of the countries in this region have experienced massive deforestation (Laurance 1999) though the FAO assessments (table 2) do not reflect that. FRA 2005 hinted that in the period 1990-2005, the area of Asian forests was stable, with an annual decrease of only 0.03%. Table 2, as an example, shows there is no change in forest area in Nepal from 2000 to 2005. But Phat (2004) mentioned that between 1990 and 2000, about 2.3 million hectares of forest were cleared every year and lost to other forms of land use. WRI (1997) claimed that 90% of the original forests have already been cleared out in Southeast Asia. Inconsistencies also persist for Bangladesh forest statistics. For example, the national estimate of forest cover of Bangladesh government source 10.3% (www.bforest.gov.bd, accessed on 15 August

Table 2: Forest cover in South and South East Asia.

South and South East Asia	**Forests in 2005 (000 hectares)**	**Forests in 2000 (000 hectares)**
Bangladesh	884	1334
Bhutan	3141	3016
Brunei Durussalam	288	442
Cambodia	11541	9335
India	67554	64113
Indonesia	97852	104986
Laos	16532	12561
Malaysia	21591	19292
Maldives	1	1
Myanmar	34554	34419
Nepal	3900	3900
Pakistan	2116	2361
Philippines	7949	5789
Singapore	2	2
Sri Lanka	2082	1940
Thailand	14814	14762
Timor-Leste	854	507
Viet Nam	11725	9819
Total	**297380**	**288579**

2006) is almost the same as the FAO state of world forest (FAO 2005b) estimate for the year 2000 (i.e. their estimate is 10.2%). In another report, i.e. FRA 2005 (FAO 2005) presented this figure as 6.7 for both the years 2000 and 2005. So, inconsistencies persist from global to regional level forest estimates. The above indicates some of the deficiencies in the existing sources of statistical information at the global and local levels. This highlights the urgent need for reliable local-national scale forest resource data, particularly if such data become integrated into global data sets by organizations such as FAO and IPCC. Recent advances in remote sensing technology offer considerable opportunities to help improve our understanding of forest resources and their distribution. The state of Bangladesh forests provides an interesting case study to evaluate the nature and causes of change in forest resources because deforestation is clearly evident from the field but there is little evidence of this from statistical sources. In parts of the country forest resources are an integral part of the economy but little is known about the dynamics of change. The nature of the study area in central Bangladesh selected for detailed study is discussed more detail in chapter 4.

1.3. Justifications of the Work

1.3.1. Remote Sensing Application

Statistics on forest cover in Bangladesh are based on approximate estimates and the published figures show significant differences (Farooque 1997); Bangladesh Forest Department claims the total area of forest in Bangladesh is about 2.53 million hectares (BFD 2001); USAID puts the figure at 1 million hectares (USAID 1990). Shin (in press) recently mentioned that only 0.8 million hectares or 5.8% of the total land area is in reality forested in Bangladesh. Therefore, it is clear that official forest estimates are either wrong or misleading. This information is used in assessing resource condition and eventually in policy formulation. Sometimes information is produced in a fashion to hide the truth from the public. For instance, there is a tendency that local forest offices exaggerate information and forward this to the headquarters in order to show that local level operations / activities are progressing well and that the forests remain in good shape; this information finally contribute to develop national forest statistics and these are, afterwards, transmitted to international organizations like FAO to generate global forest estimates (Choudhury 2006). So it can be said that unreliable information have multiple effects from local forest management to global forest estimate formulation. Official information can not easily be contested by other institutions/researchers in Bangladesh due to the lack of particular know-how and resource (financial and technical) limitations or for the lack of other alternatives to produce/access information. Therefore, most of the research works are based on official information although some researchers have expressed their doubts (Salam and Kabir 2001, Shin, in press) about quality of forest statistics. For example, the forest area in Madhupur thana, which is the study area for this thesis, is 18000 hectares according to the official statistics and this figure has remained the same for the last 10 years (Gani 1990, BFD 1999). Remote sensing, considering the above mentioned issues, is a very powerful and promising tool to help provide an independent source of tropical forest cover data which can also assess forest cover change e.g. Lucas *et* al. (2000a 2000b), Nelson *et* al. (2000), Houghton (2001) Lu (2005).

1.3.2 Application of Political Ecology

In the second component of the thesis, theoretical framework of 'political ecology' has been employed to evaluate the causes of deforestation and to help assess the impacts of afforestation (i.e. the social forestry) in Bangladesh. In political ecology, problems are viewed in a broader context rather than blaming on proximate and local forces; ecological systems are seen as power-laden rather than politically inert. Researchers in Bangladesh generally consider the immediate forces like population pressure, poverty as the causes of deforestation (Gani 1990, Mahtab and Karim 1992, Islam 2000, FMP 1993, Salam and Kabir 2001, Asian Development Bank 2001a) and rarely delve deeply into the problem (i.e. the root causes) like sources of local conflicts in the forests, impacts of government policies, ill-motivation and role of different powerful actors in deforestation. Considering only the immediate causes of deforestation resulted in formulating donor aided projects like social forestry. This social forestry is seen as a means to address the problems like poverty alleviation and nature conservation at the same time. But this project (social forestry), in turn, creates more problems in the area and complicates the situation. It is evidenced that components of social forestry (e.g. agroforestry, woodlot plantation, buffer zone plantation) caused deforestation in the area and the benefits are skewed to the powerful people in the society (Gain 2002). It should be noted that social forest is not a forest if FAO forest definition (FAO 2005) is considered, where they (FAO) clearly excluded social forest from forest definition. Considering that it can be said that the government is pursuing non-forest activities in the forest.

Government political decisions like setting up security installations by clearing out forests, converting forest and use to office parks, developing physical infrastructures (like roads, concrete walls, hotels and rest houses) in the name of eco-park, pervasive corruption of the officials, population migration policies are left unseen in assessing the causes of deforestation in the area. Political ecology can play an important role in this regard as it considers the root causes as to evaluate deforestation process (see chapter 3 for more discussion on political ecology). Most important thing is, this theoretical framework (i.e. political ecology) allows integration of human-environment (remote sensing and political ecology in the case) approach in geographical research (Walker 2005). Authors like Blaikie (1985), Blaikie and Brookfield (1987), Chambers (1983), Miller (1994), and Tisdell (1988) argue about the need for effective inter-disciplinarity to tackle environment/development problems. As Piers Blaikie (1995) comments, 'environmental issues are by definition also social ones, and therefore our understanding must rest on a broader, interdisciplinary perspective that transcends institutional and professional barriers'. The same call is echoed by Miller (1994) as he puts emphasis on the collaboration between the natural and social sciences. This cross discipline cooperation is necessary for facing the challenges that come from various sources like problems of data and measurement, problems with the ways in which research questions are framed and to avoid bias and unrealistic expectations (Tisdell 1988).

1.4. Aims and Objectives

1.4.1. Aims of the Research

This research has two major aims, i) to assess the land area covered by moist deciduous forest resources and measure change over a forty year period, and ii), to better understand the underlying social causes of forest land degradation. The first relates to the mapping of sal forest land cover in central Bangladesh using both historical and contemporary remote sensing techniques in order to make a quantitative assessment of forest change; this approach is considered as a possible alternative to official statistics. The second aim deals with the human/social factors that have fuelled forest degradation, employing the theoretical support of political ecology at this human-physical interface research. To attain these aims of the research, the following objectives are set:

1. Assemble a suitable time series of imagery.
2. Identify the appropriate remote sensing techniques (classification scheme and field methods) to produce forest / non- forest map.
3. Find out a suitable social science method so that causes of deforestation can be revealed.
4. Find out suitable approach for integrating physical and human geography methods (i.e. remote sensing and political ecology) so that deforestation problems in the study area can better be understood.

1.5. Research Questions

Some research questions need to be answered to meet the objectives. These questions have guided the development of appropriate remote sensing and social survey techniques and methods for the study. They are as follows,

1. How can the information content in the remote sensing images can be used in forest assessment?

3. Why is image resolution necessary for attaining the objectives of the research?

4 What are the sample plot selection criteria and methods?

5. What precision level should be met in using satellite sensor data for tropical deciduous forest mapping and classification?
6. How can political ecology help to assess the social variables that impact on forest resources and why is political ecology important in this attempt?
7. What are the immediate and root causes of deforestation?
8. What are the challenges in methodological integration?

1.6. Organization of the Thesis

The thesis consists of nine chapters. Chapter 1 describes the background of the research, including the aims and the objectives to be achieved. It also justifies the utility and rationale of the human-environment interface research to address the forest degradation problems in the study area.

Chapter 2 and 3 gave literature review on two major methods of this study i.e. remote sensing and political ecology respectively. The discussion in chapter 2 helped to understand the remote sensing approaches in the context of other relevant works. Specially it illustrates the post-classification comparison method used to reveal change in the study area. Similarly, chapter 3 discussed theoretical background of political ecology which is used in this work to relate the deforestation problems within a wider array of socio-political factors. The chapter also sets the rationale why political ecology is necessary for this study.

Chapter 4 outlined the description about the study area with maps and tabular data. It gave a brief description on Bangladesh forests and the discussed the forest management approaches in the study area.

Chapters 5 described the data and methods used for this research for both remote sensing and political ecology. This chapter described technical properties of satellite imagery and illustrates the data collection and processing methods. It also gave an overview about the epistemological framework of the work – this is important since the work uses methods drawn from both science and social science.

Chapter 6 demonstrated the results of remote sensing analysis. Two major components are presented here; (i) temporal change detection using time series data and (ii) assessment of forest structural variables. The modelling results presented in this chapter used the state-of-the-art remote sensing techniques to generating information on environmental indicators for better environmental management. It was stressed that further research is needed before recommending the method for assessing structural properties in other parts of the forests. But the results on temporal change detection gave clear indication of change. Accuracy assessment of classification results was also discussed in this chapter. At the end of this chapter, a detail discussion is given highlighting most of the merits and demerits of remote sensing application.

The root causes and contextual aspects of forest degradation (i.e. political, social, cultural and economic) are discussed in chapter 7. This Chapter presented the human dimensions of deforestation problems in the study area by revealing the underlying causes such as land ownership disputes in the woods, land conversion in the name of government policy implementation and corruption issues. The chapter also reflects the attitudes and participation of locals about the current forest management approaches (i.e. the agroforestry and woodlot plantations).

Chapters 8 and 9 summarise the work. Chapter 8 argues how remote sensing and social science (i.e. human-physical approach) tools can work together to deal with forest degradation problems in the global South. This chapter shows that forest degradation, based on remote sensing results, is the results of ineffective policy implementation and human interference in the study area. The chapter established the link between the patterns of processes of deforestation and suggests that, without accurate and timely information and without understanding the social factors, achieving environmental sustainability is nearly impossible. Finally, chapter 9 re-evaluates the objectives of the research and focuses on the outcome of the thesis. It also indicated the areas of further research.

1.7. Conclusion

The application of remote sensing in forest inventory and modelling is quite new in Bangladesh. On the other hand, the underlying causes of deforestation have not been viewed / assessed within the wider socio-political context. Both these approaches have a role to play in assessing rapid deforestation / degradation in Bangladesh. The condition of moist deciduous sal forests located in the central parts of the country is the worst among all the categories, with the government admitting that 66 per cent of the land in the area is tree less (Gani *et* al. 1990a), but my work shows that the scenario is much worse than this claim. My work indicates that adopting a human-physical integrated approach can shed considerable light on the problem, help to stop further degradation, and facilitate steps for regeneration and effective conservation for the benefits of both society and the environment.

Chapter 2
Literature Review: Remote Sensing

2.1. Introduction

This chapter introduces the ideas underlying the use of remote sensing in forestry research. It is intended to demonstrate the relevance of remote sensing data and methods and to show how they can be used in this particular application. Some specific definitions and methods adopted by the Bangladesh Forest Department and other international agencies in classifying forests are also outlined in this chapter.

2.2. Spectral Reflectance Curve

In remote sensing, information about an object is obtained by a sensor without physical contact with that object (Lillesand *et* al. 2004). The sensors generally records information from the spectral reflectance of the object. The optical wavelength region is most widely used and important part in the electromagnetic region for Earth observation and environmental monitoring. The optical wavelength region is further subdivided as follows:

Table 1: Wavelengths in different spectral bands.

Name	**Wavelength (mm)**
Optical wavelength	0.30-15.0
Reflective 1. Portion Visible 2. Near IR 3. Short wave IR	0.38-3.00 0.38-0.72 0.72-1.30 1.30-3.00
Middle IR (Thermal, Emissive)	7.00-15.0

Source: www.gisdevelopment.net, accessed on 15th August 2006.

The spectral reflectance of a vegetation canopy varies with wavelength (Curran 1985). A graph of the spectral reflectance of an object as a function of wavelength is termed a spectral reflectance curve (Lillesand *et* al. 2004) (figure 1).

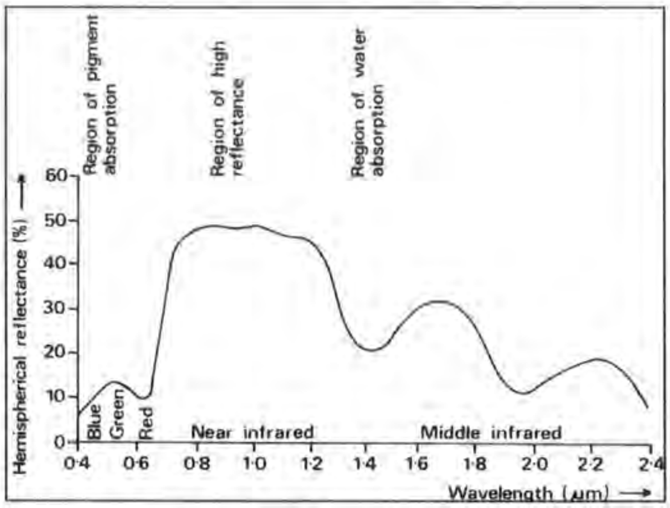


Figure 1: Spectral reflectance curve. Source: Curran (1985).

In remote sensing image interpretation, it is clear that the spectral response of vegetation is distinct from common inorganic materials (e.g. asphalt roads, buildings). The reflectance for vegetation rises abruptly at about 0.7 μm, followed by a gradual drop at about 1.1 μm (figure 1). Vegetation canopy reflects more in certain

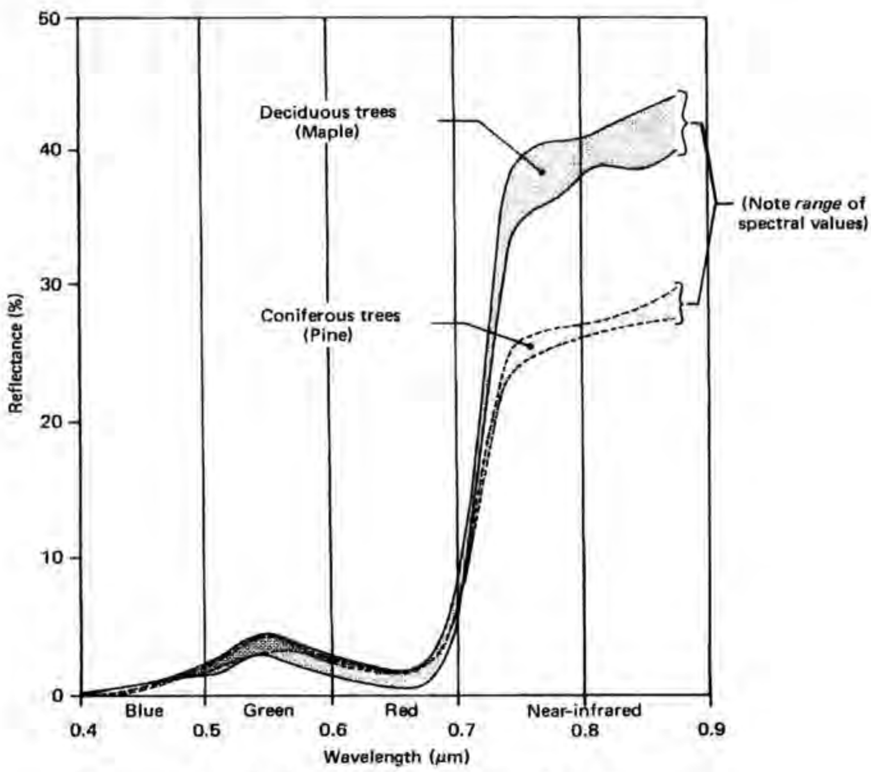


Figure 2: Difference in spectral reflectance properties between broad-leaved deciduous and needle-bearing coniferous trees.
Source: Lillesand *et* al. 2004.

wavelengths than others as seen by their hemispherical reflectance properties (Curran 1985). Jensen (1983) noted that pigmentation, physiological structure and water content determine the reflectance, absorbance and transmittance properties of green leaf. Spectral reflectance varies with the variation of plant species (figure 2). These spectral data can be used to separate forest from non-forest land use and in ideal conditions it may be possible to identify species from reflectance data.

2.3. Application of Remote Sensing in Forestry Research

Definitions and directions of appropriate tropical forest policies must be supported by reliable and up to date information about forest type, quality, distribution (Mayaux *et* al.

1998). Lack of this information on land cover resulted in costly failure of many forest rehabilitation projects in the tropics (Apan 1997). Forest inventories, mainly undertaken by state forest authorities, are conducted for gathering such information. But precise and timely data collection is an expensive process (McRoberts 2005). To overcome the cost issues and other associated difficulties, some researchers propose the application of remote sensing methods in national forest inventory (Katila and Tomppo 2001, McRoberts 2005). Much of the research work and advancement in practical remote sensing applications for forestry have focused on the Europe and North America in three major areas (i.e. measurement, estimation and mapping). In contrast, remote sensing applications in tropical countries like Indonesia (Foody *et* al. 2001), Philippines (Apan 1997), Costa Rica (Azofeifa *et* al. 2001), Brazil and Cameroon (Lucas *et* al. 2000a and 2000b, Houghton *et* al. 2001) are mainly based on forest mapping and change detection analysis. Lucas (2000a, 2000b) used NOAA AVHRR satellite data to map tropical forest regeneration in the Brazillian Legal Amazon and mapped regenerating and mature forest in Cameroon to facilitate estimation of the carbon sink associated with tropical forests. Foody *et* al. (2001) reported that scientists are uncertain about the forest dynamics (like forest biomass estimation) in the tropics. He further mentioned that there have been some studies of tropical forest environments but they are focused on major land cover conversions and the more subtle modifications are often ignored or mis-represented. Another important gap in tropics is the use of appropriate techniques for forest resource assessment. The techniques that are suitable to assess forest variables in temperate or boreal forests may not be suitable in tropical regions (Lambin 1999).

2.4. Remote Sensing Applications in Tropical Forest Inventory / Research

Forest estimates are carried out to estimate area, volume, condition, growth, mortality, removals, trends and forest health (McRoberts 2005). Finland is a pioneer in conducting such forest inventory using remote sensing methods (Katila and Tomppo 2001). Several other countries are now testing remote sensing methods in their own forest inventories. In tropical and sub-tropical countries, attempts have been made to estimate some of the forest variables mentioned above in areas such as Amazon and African (i.e. Cameroon) forests (Lucas *et* al. 2000a and 2000b, Nelson *et* al. 2000, Houghton, 2001, Lu 2005). They gathered forest biophysical information from sample plots to map forest regeneration stages and to measure stand structure estimates to ascertain above ground biomass. Nelson *et* al. (2000) argued that the study of above ground biomass is very problematic in moist tropical forests because of its complicated stand structure and abundant species composition. Houghton (2001) compared different methods to derive the best estimates of above ground biomass. Foody (2001), in a study in Borneo, suggested that an artificial neural network is one of the best methods to assess forest biomass. He compared 230 vegetation indices to find the most suitable technique for tropical forests. Boyd (1999) suggested that mid infrared (3.0 – 5.0 μm) data may be more sensitive (if suitably corrected) to changes in tropical forest properties than the reflectance in visible and NIR wavelengths. Atkinson (2000) emphasized the need for ground data collection for full and accurate characterization of remotely sensed data to map or measure tropical forest conditions. But for understanding the forest change conditions, Lambin (1999) suggested that a change analysis should cover for at least a few decades in tropical regions for any meaningful inference.

Very few studies of forest inventory in tropical countries are directly relevant to this research. Kaphley (1999) conducted a forest inventory in Nepal to calculate stand volume for different classes. He collected dbh and height measurements from sample plots and obtained wood volume by using the equation for *Shore robusta* tree species used by Nepal Forest Department. In Bangladesh, the first ever forest inventory using remote sensing techniques was conducted by Islam (1993) in the mangrove Sunderbans. He mainly used aerial photographs to estimate tree volume for Sundri (*Heritiera fomes*) and Gewa (*Excoecaria agallocha*) tree species. Islam concluded that mean tree volume per hectare (for both the species combined) was found to be 344.78 m^3/ha +/- 50.80 m^3 in Sharonkhola island in the Sundarbans. In the second study, Islam (2002) conducted another forest inventory in sal forests located in the north western part of Bangladesh under Dinajpur forest division. Using mainly aerial photographs, he showed that the sal forest in that region reduced from 66894 hectares (in 1975) to only 5552 hectares (in 2000). In both the cases he collected dbh and height information from sample plots.

2.5. Some Definitions Associated with this Study

Some definitions about forest (land use) class, management approaches in Bangladesh need to be illustrated before any remote sensing analysis is carried out. Forests are not classified in Bangladesh in terms of biophysical / structure quality rather areal estimations stand for a legal / administrative boundary. The adopted 'forest' definition of Bangladesh Forest Department (BFD) also includes areas that are without trees and thus forest statistics are being produced incorrectly compared to the forest class definitions approved by FAO or IUCN or TREES programme. However, for a clear understanding of the current forest management approaches in Bangladesh the following definition would help.

2.5.1 Definitions in Practice by Bangladesh Forest Department

Forest Land: According to the Forest Act of 1927, the lands with tree cover and the lands which are recorded in the name of Bangladesh Forest Department are treated as forest land. This definition is still in use. Those areas where plantations of trees are located on the government estates, and premises of public institutions are also classified as forest land (BFD 1990, Farooque 1997).

Reserved Forest: This type of forest is described in the Forest Act of 1927 as those lands where Government may constitute any forest land or any land suitable for afforestation which is the property of Government. The Government is entitled to declare these areas as reserve forests.

Protected Forest: The Government may declare any public forest as protected forest which is not included in reserve forest to control or preserve or protect forest products of the area and to prohibit all activities.

The forest definitions were primarily defined in 1927 (through the Indian Forest Act 1927) and adopted by the BFD without any fundamental change/adjustment. According to the current forest definitions, the total forest area of Bangladesh is about 2.53 million hectares (table 2). In another report, BFD (1990) reported that only 42 percent (0.93

million hectare) of the forest land is covered with trees and the rest are treeless or barren; about 73,000 hectares of forest land are illegally occupied by shrimp cultivators. These statistics show that there is considerable uncertainty in forest statistics. In addition, the hot spots of degradation are not identified. It is a common tendency of Bangladesh Forest Department not to deliver information/maps on the existing resources and very often they are reluctant to acknowledge the problems.

Table 2: Forest statistics of Bangladesh.

<table>
<tr><th colspan="2">Type of Forest</th><th>Area in million Hectares</th><th>Percentage on total Land Area</th></tr>
<tr><td rowspan="4">Government Forest</td><td>Hill Forest</td><td>0.67 (4.65%)</td><td rowspan="4">10.54</td></tr>
<tr><td>Natural Mangrove Forest</td><td>0.60 (4.09%)</td></tr>
<tr><td>Mangrove Plantation</td><td>0.14 (0.97%)</td></tr>
<tr><td>Sal Forest</td><td>0.12 (0.83%)</td></tr>
<tr><td colspan="2">Unclassed Forest</td><td>0.73</td><td>5.07</td></tr>
<tr><td colspan="2">Village Forest</td><td>0.27</td><td>1.88</td></tr>
<tr><td colspan="2">Total</td><td>2.53</td><td>17.49</td></tr>
</table>

Source: Bangladesh Forest Department 2001.

JRC (Joint Research Commission of the European Union) adopted forest class definitions followed by FAO forest resource assessment exercise using two parameters: *tree cover* (canopy density within a forest stand) and *forest proportion* (forest stand density within the mapping unit) (Achard 2002). Therefore, the definition of forest of JRC is *an area assigned to one of the forest classes that had a forest proportion of more than 40% in which the forest stands have a tree cover of more than 10 %.* Table 3 describes the functional definition of forest classes.

Table 3: Forest Class Definition

Forest Class	**Forest Proportion**	**Tree Cover**
Natural Forest		
Close Forest	At least 70%	>40%
Open Forest	At least 70%	Between 10% – 40%
Fragmented Forest	Between 40% - 70%	-
Non Natural Forest		
Mosaics	Between 10%- 40%	-
Shrub/Grassland/Agricultureland	10%	-
Plantations/Forest Regrowth	-	-

Source: Achard 2002.

This study, therefore, will map the forest resources of Bangladesh located in the central parts and will attempt to quantify its quality using remote sensing and field data. In order to do this, there is a need to adopt some definitions to generate forest classes based on satellite data.

2.6. Conclusion

This chapter focused on the remote sensing applications in forest research. The discussion indicated that remote sensing application in developed countries is more advanced compared to tropical countries. In Bangladesh progress has been slow to develop. This slow pace of technological application in forestry research in Bangladesh left a vacuum of information on forest resources. The chapter also reviewed the classification methods used by different researchers and focused on the necessity of accuracy assessment. Finally, it can be said that the discussion may help to put the remote sensing analysis exercises in context.

Chapter 3
Literature Review: Political Ecology of Human-Nature Research

3.1 Introduction

This chapter focuses on the theoretical understanding of political ecology, in the context of how it helps to understand problems of deforestation and official afforestation schemes in the study area and within a wider contextual framework. It is important to recognise the impact that the actions of different actors can make and to better understand their motivations.

Are environmental problems, in the contemporary world, intrinsic or constructed or is it a struggle between species or a struggle among bureaucrats, legislators, trading companies, environmentalists and scientific experts that give shape to the natural landscape? Some of these struggles, debates are appearing in our society over actions for the amelioration of nature at a time when the fate of the natural world is becoming more fragile. Researchers/theorists from different disciplines (e.g. geographers, anthropologists, sociologists, historians, agricultural economists) have been trying to figure out the causes and consequences of ecological problems for several decades. Most theories are rather limited in their approach to the human-nature interface when analysis of the problem really deserves a multidisciplinary approach. Research is also contingent upon the socio-economic, cultural, technological context within which it is produced (Said 1978) so that our theoretical tools handicap the way we perceive the global ecological crisis. By way of example, Ulrich Beck has described the 'Risk Society', where he argued that we are now living in a fundamentally different type of society (a transitional society between classical industrial and modernity) where conventional models of modern society cannot capture the origins and consequences of environmental problems (Beck 1991). Beck outlines the characteristics and consequences of the threats and dangers generated by the processes of modernization and industrialization (termed *reflexive modernization*), focusing on the ways in which they alter the classical industrial society, and what in turn has generated them. More discussion of Beck's work is given later in this chapter but first we must ask a key question. Are the present environmental problems conceptual or theoretical, economic or ecological? These are the premises that political ecologists and environmental pragmatists are using to crystallize a new set of tools that can exhume the chains of action to reveal the inherent factors responsible for environmental degradation or the breaking up of ecological systems. The tools of the political ecological approach try to recognize and expose environmental change by seeking an answer to the question "why has the environment changed and how are the terms of change defined and by whom?"

3.2 Defining Political Ecology

In political ecology, problems are viewed in a broader context rather than blaming them on proximate and local forces. Ecological systems are seen as power-laden rather than politically inert. At its core is the centrality of politics in attempts to explain the interactions between people and the environment; as Bryant and Bailey (1997) have mentioned, this 'puts politics first' in explaining third world environmental degradation.

The field has attracted several generations of scholars from the fields of anthropology, forestry, development studies, environmental sociology, environmental history, and geography. Its many practitioners analyse the relationship between economics, politics, and nature but come from varying backgrounds and training. A review of the definition of political ecology from its early use (first coined by Wolf in 1972) to the recent manifestations shows important differences in emphasis. Blaikie and Brookfield (1987) asserted that political ecology *"combines the concerns of ecology and a broadly defined political economy. Together this encompasses the constantly shifting dialectic between society and land based resources, and also within classes and groups within society itself"*. In their definition they tried to explain environmental change in terms of constrained local and regional production choices within global political economic forces, largely within a third world and rural context. Watts (2000) describes the task of political ecology as "to understand the complex relations between nature and society through a careful analysis of what one might call the forms of access and control over resources and their implications for environmental health and sustainable livelihoods". Political ecologists are therefore illustrating the political dimensions of environmental narratives and in deconstructing particular narratives they suggest that accepted ideas that simple linear trends of degradation predominate may be incorrect (Stott and Sullivan 2000).

Political ecology has emerged as a challenge to apolitical approaches of explaining environmental problems, like land degradation, local resource conflict, or state conservation failures. The most prominent of apolitical approaches are the "ecoscarcity" and "modernization" accounts of these issues (Robbins 2004). Humankind's growing numbers, following from Thomas Malthus's (1793, edited and presented in 1992) *Essay on the Principle of Population,* is blamed in a straightforward way for environmental problems without any political gloss. This argument took many forms during the twentieth century, from the "population bomb" of Paul Ehrlich (1968) to the Club of Rome's "Limits to Growth" (Meadows et al. 1972), but the elements are consistent. All hold to the ultimate scarcity of non-human nature and the selfishness of overpopulation. But the demographic explanation is a consistently weak predictor of environmental crisis and change, as argued by Robbins (2004). This is, firstly, because the mitigating factors of affluence and technology (Commoner 1998) tend to overwhelm the force of crude numbers. A very small number in the global village consume the majority of its resources. When these factors are considered, overpopulation, to the extent that such a thing exists on a global or regional scale, appears to be a problem strictly of smaller, wealthier populations, especially the United States, rather than the apparently larger populations of the global south.

In addition, market optimists try to explain natural resources problems in economic terms, suggesting that any form of resource scarcity creates a response that averts a serious crisis. As a good becomes scarcer, economists suggest, its price tends to rise, which results either in the clever use of substitutes and new technologies to increase efficiency, or a simple decrease of demand for that good. The result is that apparently finite resources are stretched to become infinitely available as consumers use less and producers supply more efficient alternatives and substitutes (Rees 1990). In this sense, resources are constructed rather than given; they are over-exploited to increase benefits per unit of resource. Hence, population control in the south, rather than requiring the reconfiguration of global distributions of power and goods, is the solution to many ecological problems in the apolitical approach. The continued advocacy of an apolitical natural limits argument is in fact essentially political, since it holds implications for the distribution and control of resources.

These approaches to environmental management and ecological change generally assert that efficient solutions, determined in optimal economic terms, can create "win-win" outcomes where economic growth (sometimes termed development) can occur alongside environmental conservation, simply by getting the prices and techniques right (Robbins 2004). For global ecology, such an approach suggests several general principles and polices. (1) Western/northern technology and techniques need to be diffused outwards to the underdeveloped world. (2) Firms and individuals must be connected to larger markets and given more exclusive property controls over environmental resources (e.g., land, air, wildlife). (3) For wilderness and biodiversity conservation, the benefits of these efficiencies must be realized through institutionalizing some form of valuation; environmental goods like wildebeest, trees or air quality must be properly priced on an open market.

There are serious conceptual and empirical problems in these approaches. First, the assertion that modern technologies and markets can optimize production in the underdeveloped world, leading to conservation and environmental benefits, has proven historically questionable. The experience of the green revolution, where technologies of production developed in America and Europe were distributed and subsidized for agrarian production around the world, led to serious environmental crisis: exhausted soils, contaminated water, increased pest invasions (Lal *et* al. 2002). Beyond these failings, the more general claim that superior environmental knowledge originates in the global north for transfer to the global south is in itself problematic, reproducing as it does paternalistic colonial knowledge relations and as *a priori* discounting of the environmental practices of indigenous and local communities (Uphoff 1988).

3.3 Considerations of Political Ecology

Political ecologists make some common assumptions when evaluating any problem. Bryant and Bailey (1997) have, for instance, argued that environmental change and ecological conditions are the products of a political process. This includes three fundamental linked assumptions in approaching any research problem. Political ecologists: "accept the idea that costs and benefits associated with environmental change are for the most part distributed among actors unequally (which inevitably) reinforces or reduces existing social and economic inequalities (which holds) political implications in terms of the altered power of actors in relation to other actors" (Bryant and Bailey 1997). Political ecological research tends to reveal winners and losers, hidden costs, and the differential power that produces social and environmental outcomes. Robbins (2004), therefore, suggests some basic questions that political ecologists consider, such as: What causes regional forests loss? Who benefits from wildlife conservation efforts and who loses? What political movements have grown from local land use transitions? In addressing these issues, political ecologists use an approach that evaluates the impacts and influence of variables acting at a number of scales, each related within another, with local decisions influenced by regional policies, which are in turn directed by global politics and economics. Therefore, political ecology appears to describe empirical, research-based explorations to explain linkages in the condition and change of social/environmental systems, with explicit consideration of relations of power. Political ecology, moreover, explores these social and environmental changes with a normative understanding that there are better, less coercive, less exploitative, and more sustainable ways of doing things. Such research is directed at finding causes rather than symptoms of problems, including deforestation/biodiversity decline, soil erosion, landlessness, human health crises, and the more general and destructive conditions where some social actors exploit other people and environments for limited personal gain at collective cost. It is a field that stresses not only those ecological systems are political, but also that our very ideas about them are further delimited and directed through political and economic processes. As a result, political ecology attempts to do two things at once: critically explain what is wrong with dominant accounts of environmental change, while at the same time explore alternatives, adaptations, and creative human action in the face of mismanagement and exploitation.

By contrast, Bryant and Bailey (1997) employ a different approach to investigating human-environment interaction in the third world context, and they do not claim that all political ecology scholarship fits neatly within their categories. Their approaches are categorised as (i) environmental problems analysis (like soil erosion, land degradation), (ii) discussions of socio-economic characteristics (class, ethnicity, gender), (iii) reviews of regional political ecology, (iv) analyses of concepts (like sustainable/green development, hazards, disasters, vulnerability) and (v) evaluations of the role of actors (grassroots, business, state).

3.4 Other Relevant Scholarship in Human-Environment Interface Research

Parallel to the work of political ecologists, there have been other attempts to look at environmental problems. These may be crudely classified into two groups. Some scholars seem to think that we have already passed the point of no return but others, in contrast, argue that the situation is not so serious and that the claims of their antagonists are based on flawed scientific evidence.

David Goldblatt (1996) evaluated four significant social theorists, Anthony Giddens, Andre Gorz, Jurgen Habermas and Ulrich Beck, in order to assess their positions in identifying the social and structural origins of environmental degradation in modern societies. Giddens (1990) argued that the conjunction of capitalism and industrialism is responsible for modern environmental degradation, while Gorz (1980) pays much closer attention to the socio-economic consequences of environmental degradation. Gorz also explores mechanisms of environmental degradation that Giddens does not; the impact of modern consumption and environmental impact of technologies. On the other hand, the work of Habermas is mostly connected with the mobilization of environmental politics. It is clear that his points of argument are annexed from the classical social theorists (like Marx, Weber, Darkheim) since they attempted to understand the interplay of interests, ideals, and cognitive understandings of the world in the mobilization of environmental politics. Habermas (1987) examined the ways in which changing social structures have produced a new organization of economic and political interests, and how these, in turn, shape the mobilization of contemporary environmental politics. He, thus, allows us to examine the ways in which cultural change and modern moral knowledge about the environment have emerged, redefined interests and contributed to the emergence of environmentally oriented political movements (Goldblatt 1996). The position of Ulrich Beck in assessing global environmental degradation is extreme. He published *Risikogesellschaft* (1986) (published in English in 1992 as *Risk Society: Towards a New Modernity*) and achieved a dramatic impact on thinking both within social science and on environmentalism, transforming understanding of the relations between science, technological hazard and social action (Adams 2003). He put the origins and consequences of environmental degradation right at the heart of a theory of modern society, rather than considering it a side-line element. Beck suggests that there is a break within modernity, and a transition from classical industrial society towards a new (but still industrial) form of 'Risk Society'. He writes, 'this concept designates a developmental phase of modern society in which the social, political and economic and individual risks increasingly tend to escape the institutions for monitoring and protection in industrial society' (Beck 1994). Beck (1991) finally called for the *democratization of science,* the process of hazard definition and agreed standards of safety and security. Although Ulrich Beck talked about the threats, dangers and risk society in the contexts of industrial world, its relevance to the third world environmental crisis is also profound. Poverty, development issues and environmental break down in the third world are inter-connected with the first world in the age of globalization. Thus the models and concepts that emerged from many of these social theorists are crystallized to form a set of tools of political ecology.

3.5 Facing the Facts: Interdisciplinary Research in the South

McCormick (1992) distinguishes the nature of debate and actions of environmental issues in the first world from the third world. The basic difference he noted is that in the first world the environmental activists are much more concerned about the impacts of development projects on landscape and ecosystem change and pollution while in the third world it is more related to the impact of development projects (i.e. dams, flood control and irrigation projects) on indigenous and subsistence ways of life.

Pearce (1992) mentioned that the threats they (development projects) represent to the rights and interests of indigenous peoples are likely to be at least as prominently expressed as threats to biodiversity. These third world environmental crises receive less attention than they deserve from third world academicians/researchers, not because first world academicians are better able to grasp every element of the problem but because Southern researchers carry out their research in a specific direction set by aid donors, and this limits their potential to generate original outcomes (and may jeopardize their ability to represent the voices, ideas, and narratives of the third world).

Secondly, authors like Blaikie (1985), Blaikie and Brookfield (1987), Chambers (1983), Miller (1994), and Tisdell (1988) argue about the need for effective inter-disciplinarity to tackle environment/development problems. As Piers Blaikie (1995) comments, 'environmental issues are by definition also social ones, and therefore our understanding must rest on a broader, interdisciplinary perspective that transcends institutional and professional barriers'. The same call is echoed by Miller (1994) as he puts emphasis on the collaboration between the natural and social sciences. This cross discipline cooperation is necessary for facing the challenges that come from various sources like problems of data and measurement, problems with the ways in which research questions are framed and to avoid bias and unrealistic expectations (this situation is acute in the third world) (Tisdell 1988). In this regard, it can be argued that fostering third world researchers may be useful for two different reasons: (1) that their networks and collective attempts (interdisciplinary) can expose, analyse, and portray their problems in a more meaningful way; (2) that communities will be better informed about the status of their environment/natural resources through such works, and this may then in turn create pressures on the authorities to formulate less dysfunctional policies (Atkins 2006). It may lead to the appropriate management of natural resources in the global south.

3.6 Politics, Exclusion and Grassroots Movements in the South

Political economy and political ecology have long been interested in social movements of many kinds. Peet and Watts (2000) mentioned that 'much of the work theorising social movements begins with Marxism, historical materialism, and a dialectical theory of social and environmental change'. The formation of social consciousness, ideology and politics of a certain group of people, in the materialistic view, is determined and characterised by the mode of productive forces (labour and means of production such as tools and infrastructure) and organised by social relationships (kinship, lineage and class). This certain mode of production defines relations with the natural environment of that society. In the dialectical view, oppositions and conflicts (inter and intra society) in the mode of production/reproduction create societal dynamics and contradictions leading to social divisions, what classical Marxists call 'class' (Marx 1970). Class, through intensified political struggle, forms collective identities and collective agency, which then energize societal and environmental transformations.

The 'social movement' literature of recent years is far removed from classical movement theories and also from its previous geographic focus (shifts towards new social movements in the Third World, particularly in Latin America, South and South East Asia). Impacts of capitalistic domination, patterns of consumption in the contemporary cosmopolitan world, and advancement in communications have taken the place of the mode of production as class-forming agents. Some movements like the World Rainforest Movement (WRM) (http://www.wrm.org.uy/) have broken the mould of traditional patterns of campaigning and protest. The WRM's electronic platform (communication through the internet) gives thousands of world NGOs the chance to form coalitions and formulate their protests (electronic protest letters, etc.) to World Financial Institutions about their actions in general or about specific development projects. In that sense, non-visible (electronic networking, academic debates) agitation can be more effectual nowadays than physical demonstrations (like street rallies, tree hugging, road barricades, etc.). Movements are transformed from traditional trade unions and political parties to neighbourhood councils, base-level communities, indigenous associations, women's associations, human rights committees, youth organizations, and self-help groupings among unemployed and poor people (Evers 1985). The shift in form, structure and participation of the masses (in social movements), in the recent times, shows a strong change in movement theorising. The following sections shed light on some remarkable peasant movements in the global south.

Grassroots environmental movements in the third world are mainly ignited by the appropriation of natural resources by state authorities, originally by colonial governments. Although the colonial governments no longer exist, the origins of movements are still rooted in their historical legacy. The Zapatistas in Chiapas, Mexico, the Miskito in Honduras and Nicaragua (Robbins 2004), Chipko in India (Sekhar 2000, Shiva 1988, Guha and Gadgil 1995), the peasant resistance in Sarawak (Malaysia) (Colchester 1993) and in colonial Burma (Bryant 1993) have all been grounded in the state's domination of natural resource management for its own benefit. For instance, shortages of wood in Europe in nineteenth century jeopardized wood-dependent industries like ship-building. A large quantity of teak timber was therefore imported to Britain from India and Burma at that time and vast amounts of wood were used in dockyards in Goa and on the Malabar coast (Albion 1926, c.i. Guha 1983b). In addition, great swathes of forests were destroyed to meet the demand for railway sleepers. According to Guha (1983), no supervision was exercised over the felling operations and a large number of trees were felled whose logs could not be utilized. The then British government formed its Forest Department in India in 1864 with assistance of German foresters to safeguard their long term imperial interests. The first attempt at asserting state monopoly rights was through the Indian Forest Act of 1865, which was replaced by a much more comprehensive piece of legislation 13 years later (in 1878). The provisions of the 1878 Act ensured that the state could demarcate 'valuable' tracts of forests, needed especially for railway purposes, and retain enough flexibility over the remaining land to revise its policy from time to time. Indigenous use of resources was defined as 'wasteful' and purely technical solutions such as a ban on tree felling, grazing and physical fencing, were applied (Sekhar 2000). The Act asserted that the customary use of forest resources by the villagers was no longer their 'right' but a 'privilege', that can only be exercised at the mercy of local rulers. This state control over Indian forest resources caused extensive social movements in 1916 and in 1920/21, the latter coinciding with the first non-cooperation movement and engulfing large areas of Garhwal and Kumaun (in Uttaranchal province, India). These upsurges forced the government to de-reserve large forest areas (Guha 1983). After independence, disputes over the continuation of colonial forest policies (of state ownership, state regulation and revenue maximization) led to much frustration and eventually to the world famous, non-violent (mainly by women), Chipko (tree hugging) movement in 1973 (Kevin 1998) in Uttaranchal. Women embraced the trees as a Gandhian form of non-violent resistance to save them from being felled by state-authorised loggers. The movement has been successively categorised as a feminist movement, an ecological movement, a peasant movement and a cultural movement (Shiva 1986, 1989; Guha 1989, 1993; Karan 1994; Khator 1989; Weber, 1989). Like in India, the same notion (to ensure timber supply) of forest management was exercised by the colonial government in Burma, leading to peasant movements in different forms (non-cooperation, theft, breach of rules, etc.). Bryant (1993) thoroughly examined the political implications of state patronised forest management approaches in colonial Burma and explored its resultant response in the community. People from diverse groups challenged the Forest Department with the intention of preserving their forest access. The British introduced two major steps to ensure valuable (teak) timber supply from Burma. First, they introduced a fire protection programme and banned cutch (a water extract of the sha tree) production and secondly, they focused on persuading local people to generate teak through *taungya forestry*. These programmes affected local people economically, culturally and spiritually and ignited rebellions and the Anglo-Burmese wars in 1822-1826, 1852 and 1885/86.

The forests of Sarawak, Malaysian Borneo, are today the scene of a bitter struggle by the native peoples trying to maintain their land rights against a timber industry intent on felling their forests for profit (Colchester 1993). The protests of the Sarawak people (such as barricades flung up across the logging company roads) have not secured their land rights and have failed to protect their natural forest resources. Having lost their traditional economy and lifestyle, the natives became 'pirates and poachers' and, denied effective rights to their lands, they became 'squatters' on state land (ibid.). Colchester (1993), like other authors mentioned earlier, relates the roots of this social and environmental crisis with colonial past when British imperialists and merchants crushed native resistance and took control of the native peoples' lands. The forest policy of the Sarawak government and the vested interests of local and national political elites forced the native people into subordination to external economic and political powers.

3.7 Political Ecology: In Forestry Research

Exploring the *chain of causes* and revealing the inherent sets of arrangements (agents and structures) and contexts of deforestation are prime foci for political ecologists. They contribute in deforestation issues that relate to exploring local dynamics (social, economic and ecological), impacts of global capitalistic hegemony, construction of purposive narratives and truths, peasant frustration and their movements as a consequence of the colonial legacy. Blaming poor peasants, formerly a dominant view in deforestation/environmental research is now being contested all the way from grassroots movements to academic research. Fairhead and Leach (1996), Jarosz (2000), Ribot (1995), Bryant (1993), Colchester (1993), and Guthman (1997) have all rejected this *neo-Malthusian* view of deforestation in West African Guinea, Eastern Madagascar, Senegal, Burma, Sarawak in Mayaysia and Nepal respectively. Rather they describe the colonial discourse and point to the social and political construction of arguments as the causes of natural resource depletion in the global south. Most colonial governments cordoned off forests in the name of 'reserve forests' in order to exclude local people from customary resource use to ensuring imperialistic benefits. The successor independent states inherited and systematically extended the same role in resource extraction. Peet and Watts (2000) in their remarkable book *Liberation Ecology* critically examined the notions capitalistic domination on economic issues and commented that it creates environmental crisis in the third world. Arturo Escobar in the same book explained that nature and the rationale of its use, based on poststructural theory, as we see now are a social construction. He identified a tendency to see natural resources as *cash capital* and to conserve it for the benefit of that capital. The concept of *sustainable development* is rejected by him as he argues that this concept is a new form of capitalistic supremacy. Wood (1990) showed that deforestation is the result of structures and decisions by actors at a range of levels (local, national, multi-lateral and global). Fairhead and Leach (1995) critically reviewed the applied social science methods in the case of constructing deforestation narratives in West African Guinea. Their argument suggests that government bureaucrats and paid (professional) researchers produce data and reasoned arguments that justify their taking control of local resources and that exclude locals from resource use or management. Fairhead and Leach found that Western social scientists described massive deforestation in Kissidougon and Zamia (in West African Guinea) due to over-population and poor conservation strategies. But on the basis of historical documents (old traveller's notes, old maps and records), oral histories of older people and aerial photographs, they confirmed that forest cover had rather increased during the period of settlement. False narratives had been produced and used to support policy and to stabilize the prior assumptions of the donor organizations.

Regarding Amazon rainforest depletion, Hecht and Cockburn (1989) and Parayil and Tong (1998) insisted that the deforestation in the Amazon must be seen in the context of political economy of Brazil. The Brazilian government offered tax reductions for companies (including foreign companies) investing in Amazonia from 1966. These tax incentives encouraged the annexation of land by old ranchers and new speculators at a cost of rainforest clearance (Walker 2000). The current soya boom, supported by the Brazilian government, has sparked a further, massive deforestation. In the year 2004 alone, some 26,130 square kilometres of rainforest were cleared due to the activities of legal and illegal loggers, soybean cultivators and cattle ranchers (*The Independent* 20th May 2005).

Gadgil and Guha (1995) described an 'iron triangle' established by beneficiaries (urban and industrial elites), administrators/bureaucrats and decision makers/politicians (together termed 'omnivores'), who define the size, scale, terms and conditions of natural resource extraction (depletion). They argued that this coalition is mostly responsible for the current fragile state of Indian natural resources. Recent movements, media coverage and academic research have led to a *paradigm shift* of Indian forest management towards decentralization. The Indian Forest department's mega scheme, *Joint Forest Management* (JFM), is aimed to integrate people in forest management and to give them a sense of ownership (participation). It is a major move of state apparatus from a top-down (patron-client) outlook to a cooperative stance, though the people are sceptical about the actual goal of JFM. As Sekhar (2000) commented, 'it is not clear whether the JFM policy in India is an attempt to institutionalize state dominance, or if it will lead to real decentralization'. The area under JFM in 2004 was about 17.33 million hectares, involving around 62 million people (MoEF 2004). The same type of people-centred approach forest management is in operation in many other developing countries, such as: Community Forestry in Nepal (Campbell *et* al. 1987); the decentralization reforms in Mali

(Benjaminsen 1997), the Campfire approach in Zimbabwe (Hill 1991, Child 1995), and Social Forestry in Thailand (Pragtong 1993), with technical and financial support from international donor agencies. In most of the social forestry projects, fast growing plantation species (like *Acacia mangium* as monocultural afforestation) have replaced local varieties of tree species, and issues of biodiversity and ecological sustenance are ignored while aiming at providing commercial opportunities for poor smallholders. Kellert (2000) stressed that the words 'participation, decentralization, community orientation', like *sustainable development*, have become jargon in natural resource issues. He studied Community Natural Resource Management (CNRM) in Nepal, Kenya, and Alaska in order to compare six indicators (i.e. equity, empowerment, conflict resolution, knowledge and awareness, biodiversity protection and sustainable resource utilization) and found successful results in North American cases, while the results are frustrating in Nepal and Kenya. However, their comment suggests that the overall performance of CNRM is not encouraging. A review of the literature suggests that, although national governments are now realizing slowly that formal authority should be given to local users for better resource management, the results are mixed in nature.

Another important attempt by political ecologists, published in *Global Ecology and Biogeography Letters* (1993), was to explore the complex political, economic, and ecological processes that underlie developments in South East Asian forests. Bryant (1996a) shows, in this issue, how the market mechanism for Burmese wood drove a policy agenda that enforced state control for teak production by imposing regulations like banning shifting cultivation, fire control, cutch production regulation, etc. Bryant (1996b) in another paper described how the then colonial forest officers recorded the teak extraction accounts, the status of forest revenue collection and forest conservation in their documents as *progress reports* but neglected indigenous forest management approaches and political conflicts in their accounts. Papers presented by Whitmore (1993) and the Earl of Cranbrook (1993) in *Biogeography Letters* illustrate the on-going contribution of European science to an understanding and interpretation of South East Asia's tropical rainforests. Whitmore traces that contribution from the "colonial era of scientific perception" to the present (Whitmore 1993). Rigg (1993) examined how valuable teak forests in northern Thailand went under state control along with the "wilderness (that supported local livelihoods)" of surrounding villages. Lohmann (1993) explored the role of global institutional interconnectivity for land use change and associated forest degradation. He asserts that the introduction of foreign tree species in Thai forests like the Eucalyptus plantations, industrial estate expansion, and the creation of tourist resorts in the forest areas are connected with northern capital and aid, and cater to the "developed" world's demand for cheap manufactured goods, pulp and paper and recreation (Lohmann 1993). Forests are also sometimes used as ethnic dumping grounds in the name of land reform or resettlement by the state, which creates multi-faceted problems (Lohmann 1993) and this is common in many parts of the global south including Bangladesh.

Political ecologists recognize that modern information systems (i.e. Geographical Information Systems and Remote Sensing) may contribute to enhancing our ability understanding the diverse ecological processes but at the same time they are sceptical, stating "there are no guarantees that the new understanding will be put to socially beneficial use" (Bryant *et* al. 1993). It is very important, in this regard, to note that sometimes state agencies (i.e. forest department) deliberately and systematically manipulate forest/land cover data (overestimate or underestimate of land cover change or degradation) for political-economic reasons and to divert attention away from serious underlying problems (Kummer 1992; 1996). Philip Stott (1991) suggested that tools are not a big issue, rather the objective and the utility of North-South transfers of technology and scientific knowledge.

In most deforestation and forest degradation studies, poor, ignorant local communities are generally blamed, but Fairhead and Leach (1996) explored the role of decision-makers, local people, and competing interests in West African forest degradation. In the same line of understanding Hecht and Cockburn (1989) illustrated the regional political ecology of degradation in the deforestation in the Amazon. In their classic work, *Fate of the Forest*, they tried to reveal the chain of explanation from local to the global that triggered the change in the Amazon forests. Schmink and Wood (1887, 1992) argued that the degradation in Amazonian forest is the result of conflicting socio-political systems. Rocheleau's work in the Dominican Republic shows how the introduction of fast-growing, cash timber species (Acacia mangium) adversely affected the forest biotic assemblage and changed the producers' fields, pastures, and gardens (Rocheleau and Ross 1995; Rocheleau 2001).

3.8 Conclusion

Political ecology has firmly established its human-environment approach in geographical research (Walker 2005). The narratives/arguments, debates/oppositions in this field about environmental/ecological crisis have brought us to a crossroads from where ultimate directions for emancipation may be achieved. The journey towards this junction from the 1970s provides us with clear insights of why, how and by whom the environment and ecology has arrived at its present fragile state. Political ecologists from different fields with varied arguments and styles (based on theoretical support of political economy and ecological analysis) have been contributing for the last three decades to uncover the socio-political causes/influences of ecological breakdown. However, some authors (like Vayda, Moore) are cynical about the merits of political ecology in interpreting ecological problems. Vayda (1999) argued that political ecologists pay less or no attention to demonstrating ecological effects, rather they (political ecologists) are more interested to focus only on political processes. This claim is also supported by Bassett and Zimmerer (2004) as they phrased it 'politics without ecology'. Walker (2005) borrowing the results from empirical study of Mathew Turner (1998) in West Africa (on livestock size in relation to power in the society and local demand), encountered Vayda's claim and asserted that the major works in political ecology do engage biophysical ecology as a central concern. On the other hand, Moore (1993) criticised political ecologists' neglect of the impacts of the 'micro politics' that condition environmental conflict in the third world. But Bryant and Bailey (2000) reject Moore's claim and mention that his comments are not valid in the realm of current political ecology research.

There is no doubt about the significance of political ecology in human-environment research, although it is still lacking any practical route to resolve crises, rather just showing scepticism about the merits of other concepts (like *sustainable development* termed *business-as-usual* by Bryant and Bailey 2000, Hecht and Cockburn 1992). In this regard, the proposal of Gadgil and Guha (1995) for a *Conservative-Liberal-Socialism* as a tool for handling ecological problems may profitably be debated for further scrutiny and improvement/extension. In addition, environmental pragmatism (an American philosophy on environment) may also contribute significantly in resolving third world environmental problems. Environmental pragmatists advocate a 'situationist and interactionist' approach for problem solving. They stress the judgement of any proposal/concept through (different forms of) societal experiments prior to its implementation. Both approaches conceptualize the 'truth' as a social construct (political ecology relied on Foucault, see Peet and Watts 2000, and environmental pragmatists depended upon Dewey, see Atkins 2006). Therefore, solutions/policies in achieving environmental goals need to be scrutinized through community participation.

Despite real progress in academic research, the operational world (policies, sates, international bodies) is still riding Beck's (1991) runaway modernity train, where the passengers (the intellectuals) have little stomach for change. The murder of Chico Mendes, the principal spokesman for Brazil's rubber tappers in 1988 (Hurrel 1991), the slaying (in 2005, Brazil) of anti-logging campaigner Dorothy Strang (*The Independent*, 20th May 2005), and the killing of forest-protection activist Piren Slan in 2004 (in the Madhupur forest) by the Bangladesh Forest Department are some signs (among such many events around the world) that remind us that academic practitioners are far from persuading powerful actors (national governments and international agencies etc.) to perform in favour of people and nature. It is no exaggeration to comment that we will soon be undertaking forestry research in forest-free tropics if we fail to respond promptly to save the remaining trees.

Chapter 4
The Study Area

4.1. Introduction

This chapter presents a discussion on the location, physical settings, history of forest management and population characteristics of study area, i.e. the Madhupur forest. It would be useful to give a brief discussion on Bangladesh forest before giving any accounts on forests located in Madhupur. It may also help to set the study area in to the national context.

4.1.2 Forests of Bangladesh

The actual forest cover in Bangladesh is based on approximate estimations (Farooque 1997) and the figures vary. A report by USAID finds one million hectares or about 6 percent of the country's total land area (USAID, 1990) under forest. According to an estimate by the Bangladesh Forest Department in 1990, the area under forest is 2.46 million hectares (FAO/UNDP, 1990). These forests are unevenly distributed and mainly concentrated in the south and south-eastern parts of Bangladesh. The per capita forest land is about 0.02 hectare, which is one of the lowest such ratios in the world.

The forests under the control of the state Forest Department are of four ecological types, namely:

(i) Tropical evergreen forests

(ii) Tropical semi-evergreen forests

(iii) Moist deciduous forests, and

(iv) Mangrove/ Tidal forests (The Sunderbans)

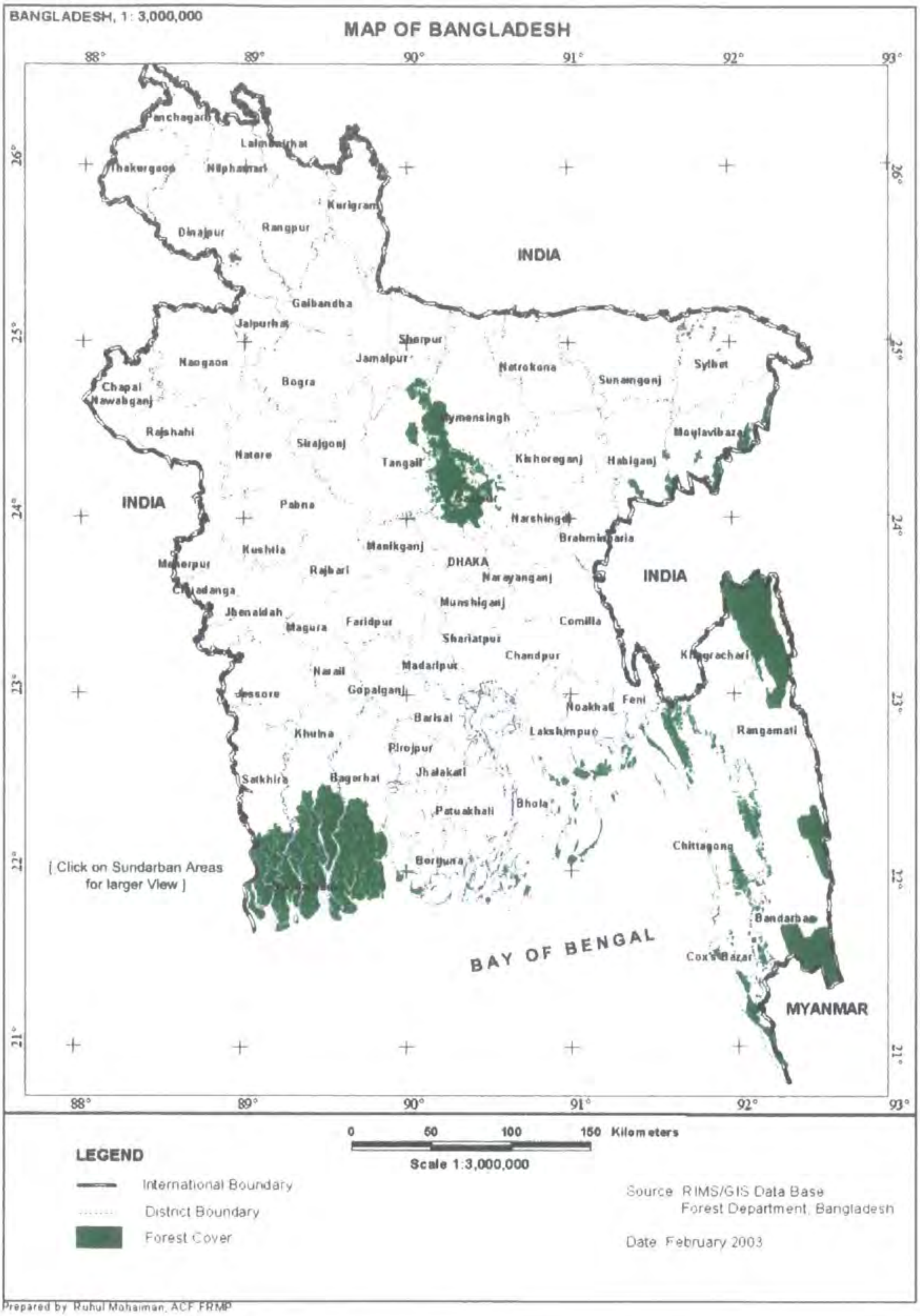


Figure 1: Forests in Bangladesh, 2005 (source: www.bforest.gov.bd).

Table 1 presents the government statistics of forest resources under different categories. In addition to the 1.52 million hectares of state forests, there is another 0.73 million hectares of unclassified (under different district administrations) state forest and 0.27 million hectares (1.9 percent) of village forests (Rahman *et* al. 2001).

Table 1: Categories of Bangladesh forests.

Types of Forest	**Area in million hectares**	**Percentage**
Natural mangrove forest and plantation	0.73	4.95
Tropical evergreen and semi-evergreen forest	0.67	4.54
Tropical moist deciduous forest	0.12	0.81
Total	1.52	10.3

Source: http://www.bforest.gov.bd/, accessed on 28th December 2005.

This study focused on moist deciduous forests located in the central parts of Bangladesh, specifically focused on the forests in the northern parts of Madhupur tract under Tangail district.

The study area falls within the sal forests of Madhupur Thana under Tangail district (figure 3). These forests are sometimes called as the *Madhupur forests* as they developed on the same soil and topographic conditions as the famous Madhupur terrace. A special feature of the topography of the Madhupur tract is that the forests are located on flat-topped hillocks (locally called *chala*) separated by an intricate network of depressions (locally called baid) in a honeycomb layout pattern (Bhuiyan, 1994). These baids are generally cultivated with paddy. Homesteads, cultivable lands and forests are inextricably mixed up, making forest boundary demarcation and maintenance extremely difficult.

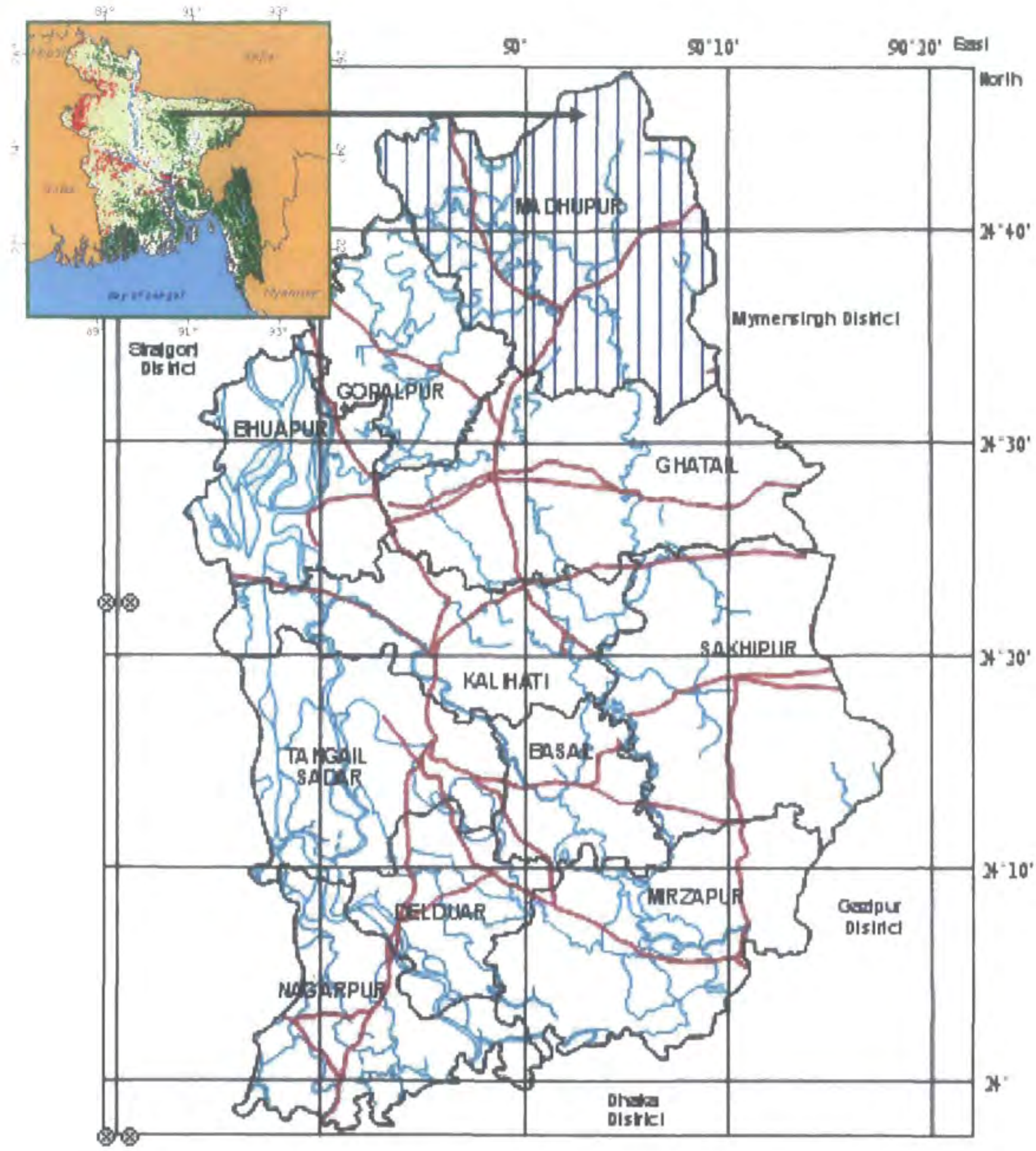


Figure 2: Study area map, Madhupur thana.

4.2. The Moist Deciduous Sal Forests

The plain land forests of Bangladesh, commonly known as gazari or sal (*Shorea robusta*) forests, are distributed in small patches in the greater Dhaka, Tangail and Mymensingh districts in the central region and in the greater Dinajpur, Rangpur and Rajshahi districts in the northern districts of the country. In the central region, the forests are also identified by two popular blocks viz., 'Bhowal Garh' and 'Madhupur Garh' and the later was historically known as 'Garh Joyen Shahi'. Among the 120,000 hectares of notified (government declared) forests under the control of Forest Department, 104,616 ha (87 per cent) are located in the central region and 15, 639 ha (13 per cent) in the northern region.

The sal forests have been classified by Champion *et* al. (1965) as 'tropical moist deciduous forest'. These are further subdivided into two sub types as moist sal forests and sal scrub forests. The moist sal forests comprise areas containing pure sal crop, mostly of coppice origin. The natural associates of sal in this forest sub-type are, bahera (*Terminalia belerica*), sil koroi (*Albizia procera*), ajuli (*Dillenia pentagyana*), haldu (*Adina cordifolia*), kumbhi (*Careya arborea*), jam (*Syzugium cumini*), haritaki (*Terminalia chebula*), arjun (*T. arjuna*). The sal scrub forests are comprised of degraded sal forests areas resulting from severe human interference through repeated felling, causing sal stumps to loose their coppicing power and thereby also rendering substantial areas treeless. The associates of sal in this forest type are bahera, jam, simul (*Salmalia malabaricum*), chatian (*Alstonia scholars*), bandarlathi (*Cassia fistula*), jiga (*Lannea coromondelica*). Although plenty of sal regenerations come under the pure sal coppice, they cannot get established due to extensive ground fires, which sweep the forest floor every year during the dry season. The ground fires are both incendiary and induced - the fires are induced by the local people to burn the dry leaves of *garjan* trees on the ground so that the ash may later be washed down to the *baid lands* (low lands) by the subsequent rain to increase the soil fertility. The young coppice shoots, besides being damaged by fires, also particularly damaged due to heavy cattle grazing by the local people during dry season when the fodder scarcity is acute.

Table 2: Forest Distribution by Thana in Tangail District.

Name of Thana in Tangail District	Forest Area (in hectares)
Basail	-
Bhuapur	-
Delduar	-
Ghatail	9752
Gopalpur	-
Kalihati	-
Madhupur	15418
Mirzapore	2022
Nagarpur	-
Shakhipur	16201
Tangail Sadar	-
Total	**43393**

Source: BBS 2003.

4.3. Madhupur Forests: Its Location and Physiography

Madhupur forest is located on the border of the Mymensingh and Tangail districts and covers areas of both districts. The current forest concentration remains mainly in two forest divisions like southern belt of Mymensingh Forest Division and northern parts of Tangail Forest Division. Madhupur forest is a part of Madhupur tract, which extends from the south western part of Mymensingh district in the north to the northern border of Dhaka district in the south.

The physiographic unit that supports Madhupur sal forests is spread discontinuously on the central part of Bangladesh. The area is dissected, unconsolidated, unfolded upland of the Pleistocene age. The homogeneity of the sediments both in vertical and horizontal directions is indicative of their estuarine origin (Hassan 1994). The hydrology of the

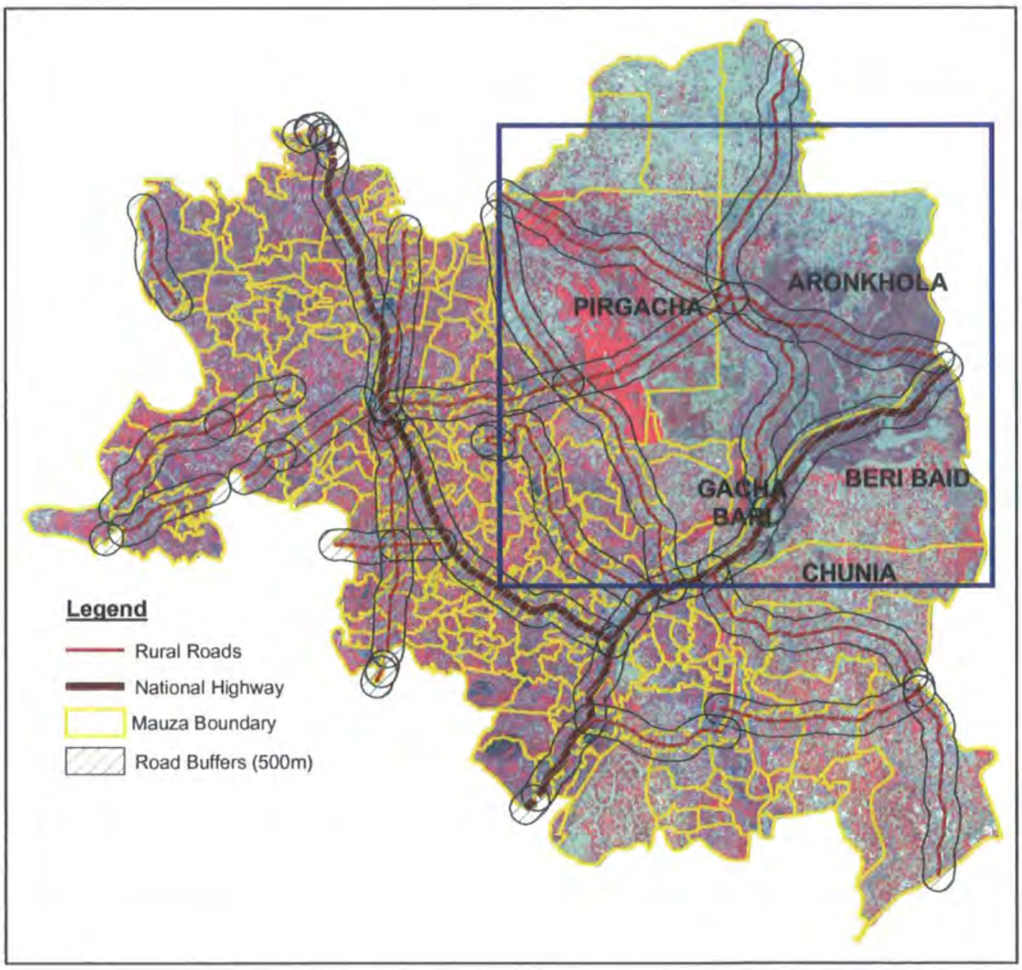


Figure 3: Natural forests and cultural landscape are intermingled in the study area, displayed in Landsat TM 1997 image. The blue box shows the main concentration of forest resources on Madhupur Thana map.

Quaternary terraces is regulated by high seasonal rainfall, fluctuating groundwater table and free surface drainage conditions. This landscape is drained out by an intricate network of valleys and creeks which ultimately converse into several local rivers. The Bansi, Banar and Dhaleshwari occur in the area as the major rivers.

4.4. The Soil Properties

The lands in Madhupur forest can be classified according to the weathering condition and landform manifestation (Mazumder 1994). The major land types are, (i) deeply weathered, (ii) shallowly weathered, undulating and (iii) shallowly weathered, flat. The soils, developed on deeply weathered terrace material on closely dissected topography, are well drained. Unlike the shallow weathered terrace soil, the depth to the unaltered pre-weathered material in these soils may vary from one to many metres. The pedogenic factor, e.g. time, relief and to a lesser extent the parent material contribute to the profile development in these soils. These factors dominantly act in forming the structural, color and textural horizon. The effect of leaching on soil reaction (pH) and base saturation is partly neutralized by the fluctuating groundwater table may reach to the surface but sinks down rapidly after the rain stops. Soils developed on deeply weathered terrace material phave a strongly structured, clayey, reddish to brownish, acid subsoil.

4.5. The climate

The climatic conditions are moderate. The temperature ranges from 15 degrees centigrade to 37 degrees centigrade during January-February and April-May respectively. The weather becomes hot during March-April. Mean annual rainfall is about 250 cm, the maximum being between the months of June and September (FAO/UNDP 1992). Mean relative humidity is high throughout the year and does not fall below 65 percent (BBS 2003).

4.6. The landuse

The chala (high lands) was used by the original residents to build their homesteads and for swidden until this cultivation is banned in the early 1950s. These lands are still used by the original residents and the new settlers for homesteads, vegetable gardens, pineapple plantations. The baid (low lands in between chala lands) lands were converted by the original residents to wet rice fields after clearing the bushes and these lands are still used for growing wet rice. Parts of deforested slopes between chala and baid lands have also been converted to wet rice fields by some people, particularly by those who occupy the baid lands adjacent to these slopes. The interior of chala lands are forested.

4.7. Forest Management Approaches in Deciduous Sal Forests in Madhupur

4.7.1 Past Forest Management

The forests in Madhupur tract were managed under the administration/supervision of the Zamindar (feudal land lord) of Natore (Bhuian 1994) during the British rule. Revenue collection for the British East India Company (and then for the colonial British Government) was the main purpose of forest land use by the forest landlord at that time. In 1865 Sir Dietrich Brandis (1824-1907) was appointed as the Inspector General of Forests in India and he, for the first time, introduced scientific forest management in the sub continent (www.bforest.gov.bd, accessed 28 December 2005). A separate forest department was created for Bengal in 1872 and this department brought sal forests under scientific management (through specific working plans) and the coppice silvicultural system was adopted for sal regeneration in the area. In the past, three methods of sal tree reproduction - natural regeneration through seeds, coppice and artificial regeneration, have been attempted in the area (MoEF 1999). With the enforcement of Private Forest Act 1945 (came into effect in 1949), the forests were brought under the direct supervision of Government of India for management. Afterwards, in order to protect the natural sal forests, a significant part of Madhupur forest was declared by the then Pakistan government as Reserved Forest and a National Park in 1955 and 1961 respectively (see table 13 in chapter six for more). The Forest Department of Bangladesh implemented its Community Forestry Project in 1982 with an Asian Development Bank loan, when native and natural forest species were officially replaced by fast growing and fuel wood producing species (such as different varieties of acacia), and this paved the way for social forestry programmes in the area later on.

4.7.2 Present Forest Management

The Forest Department is currently (for the duration of 1997/98 to 2005/06) implementing a Forestry Sector Project (FSP) with an estimated cost of US$72.858 million (financed by the Asian Development Bank) in 29 forest divisions all over the country. The aim of the project is to enhance forest resources and functions for environmental and socio-economic development. Forestry Sector Projects made up mainly with the components of woodlot plantations, agroforestry schemes and plantations in coastal islands (charlands) and roadsides and institutional premises. The Tangail Forest Division, within which the Madhupur forest is located, is one of the main areas where FSP programmes, like woodlot plantation and agroforestry, are now in operation. Gani *et* al. (1990a) have discussed sal forest rehabilitation, planning and regeneration strategies in detail. The main recommendation of this report was to replace natural forest in the area by fast growing species (Gani *el* al. 1990a, ESRU 1992). The feasibility study report of Forestry Sector Project for this forest division (MoEF 1999) also outlines sal forest management approaches for the government. Some quotations from two government planning reports are reproduced here to understand the current forest management directives of Bangladesh Forest Department.

> "…….The degradation of forests has continued due mainly to **illicit felling, encroachments, grazing and forests fires**. Although woodlot and agroforestry systems of fast growing species have been established in blanks and depleted sal forests, **no significant programme for the development of natural forests has been taken up in the recent past** (MoEF 1999)".

> "……..**The statistics of forest production in Bangladesh are unreliable**…..Efforts by Forest Department to rectify the situation have largely failed. It is now realized that under the existing socio-economic conditions, it is not possible to preserve the forest or to rehabilitate the degraded areas through the unilateral action of the Forest Department.

Participation of the people is vital if anything viable is to be effected, and **this calls for social forestry in the form of participatory agroforestry and woodlot forestry**. (Gani *et* al. 1990a)".

These government reports on deciduous forest resources indicate a major shift in forest management approach by the Forest Department, away from protection and management of natural forests to people-oriented, participatory/social forestry (figure 1). The social forestry programmes have now got real momentum and this is beginning to be reflected in forest land use pattern. However, Forest Department adopted this new approach without addressing or solving some of the key causes of natural forest degradation/depletion. *Illicit felling and encroachments* have repeatedly been reported in different media (academic, news media, institutional research) but actions against such corruption have not been taken. Secondly, the problems associated with forest land encroachments were not solved through settling the disputes over land ownership (these issues are discussed more detail in chapter five and six).

Figure 4: Natural forests (left) are replaced by agroforestry (right, pineapple gardening with acacia plantation as ally) in the study area.

One of the major drawbacks of forest management is the lack of an accurate forest inventory and maps. The general tendency of the Forest Department is to create a generalized forest maps representing only very basic information. Figure 2, shows the current forest map of the country, is an over-representation of resources. There does not appear to be a forest map of Madhupur forest, with information about the structure, quality and health of the forest which hinders to assessment, planning and monitoring of forest resources at the local level.

The remote sensing unit of the Asian Institute of Technology (AIT, Thailand) has prepared a detailed map for a study on *rehabilitation and land use planning of sal forests* (conducted by Gani *et* al. 1990a, 1990b, mentioned above) using Landsat data (from 9th March 1989) for the whole sal forest area. Gani *et* al. (1990a) reported the statistical findings of this remote sensing research by AIT but no maps were included in the main report except a generalized hand-drawn overview of forest distribution. The remote sensing data analysis revealed that only 7230 hectares of land in the Madhupur sal forest were wooded (in 1989) and the rest of the area were blanks, degraded or encroached within the previously notified total forest area of 17,381 hectares. However, the published statistics never represent actual wooded area at regional or national level but are rather the total notified area (including blanks, and degraded and encroached patches) which, under the control of the Forest Department.

The discussion above strongly suggest the need for field level forest quality assessment and mapping so that the real condition of the forest resources can be ascertained.

Planning can then be adopted and implemented on the basis of information representing the state of forest environment with the support of contextual socio-political factors that have shaped the condition of the forests.

4.8. The People

The people living in Madhupur forest belong to three different ethnic groups, Bengali, Garo and Hazong. The Bengali people are the mainstream population in Bangladesh, and in relation to them, the Garo and Hazong are ethnic minority communities. Although the Garo and Hazong are two different ethnic groups, the Bengali generally regard both people as Garo (Khaleque 1992). But the Garo peoifple distinguish themselves from the Hazong, who are ethnically different. The Garo call themselves *Mandi* and use the term *Mandai* for the Hazong. The Hazong people, however, do not use either *Mandai* or *Hazong* preferring to identify themselves as Hindus, since they follw Hindu religion. The three ethnic groups of people in Maddhupur forest differ from each other in language, religion and social organization. The Bengali language which is the mother tongue of the Bengali people and the national language of Bangladesh, is spoken by the people in all three grousing are Most of the Bengali people in the area are Muslim while the Hazong are Hindus. The traditional religion of the Garo is a form of animism, although Garos are now converted Christians.

4.9. Conclusion

Madhupur forest is unique for its physiography, soil condition and forest type. The area was once deeply covered with Shorea robusta tree species with a rich mixture of other species. The local people use low lying lands for agricultural activities. Some of the chala lands are also converted by them for pineapple and banana plantation. In recent times this forest went under a massive deforestation for various reasons. The area is chosen for this study to assess the existing forest resources and it locate the under lying cause of forest cover change.

Chapter 5
Data and Methods

5.1 Introduction

Remote sensing techniques and social science methods both contributed to this research to assess forest resources and change. Remote sensing data were used for two main purposes. First, these data helped to produce a time series (from 1962 to the present) which formed the basis of a change detection analysis. Secondly, the data were used to assess the present condition of the forest resources. These remote sensing techniques were supported with field data on forest bio-physical variables. Forest variables like diameter at breast height, average tree height of the tree, and species composition were collected from selected sample plots and other variables such as basal area and volume were calculated in the laboratory using the Bangladesh Forest Department's standard methods. These field data helped to define training areas for spectral signature classes for image classification. Secondly, field data on forest biophysical variables helped to assess current forest resources in quality terms. Data gathered by a Global Positioning System (GPS) helped to geo-rectify the images. In addition, key informants (appendix 3) were used to help verify the past occurrence of forest resources based on initial classification maps, during the field visit in 2003/2004. Remote sensing data collected by Corona KH4, Landsat (MSS, TM, ETM+), ASTER, IRS LISS-III and Quickbird satellite sensors are used in this research. Some vector GIS data were also used as an aid to the remote sensing analysis. No new remote sensing methods were developed in the study rather established techniques such as supervised and unsupervised classification, regression analysis were used to assess forest resources in the study area.

In the second component of the thesis, social variables are evaluated to establish the social complexities that have caused deforestation in the area. It is vital to assess the social factors as deforestation is a result of human interference and policy failures rather that 'natural' causes. A questionnaire survey was conducted with the local people living in and around the forest in Madhupur. Some in-depth interviews were also undertaken with key informants. Besides, a review of historical documents revealed the historical legacy of the change of the forest. Current forest policies were also cited for a clear understanding. The theoretical framework of political ecology is used to structure and analyze the social variables (for more discussion, please see chapter five and six).

This chapter mainly focuses on the data used (remote sensing and social science), their properties and collection methods. Discussion of remote sensing data and properties is emphasized in this section as social data collection methods and their nature are discussed more fully in the respective social science chapters.

5.2 Sources of Data

5.2.1 Remote Sensing Data

5.2.1.1 Corona Data (1962)

Corona was the first operational space photo reconnaissance satellite programme (http://www.fas.org/spp/military/program/imint/corona.htm, accessed on 06 February 2006). The project was conceived to take pictures from space of the Soviet bloc countries and return the photographic film to Earth for processing and exploration.

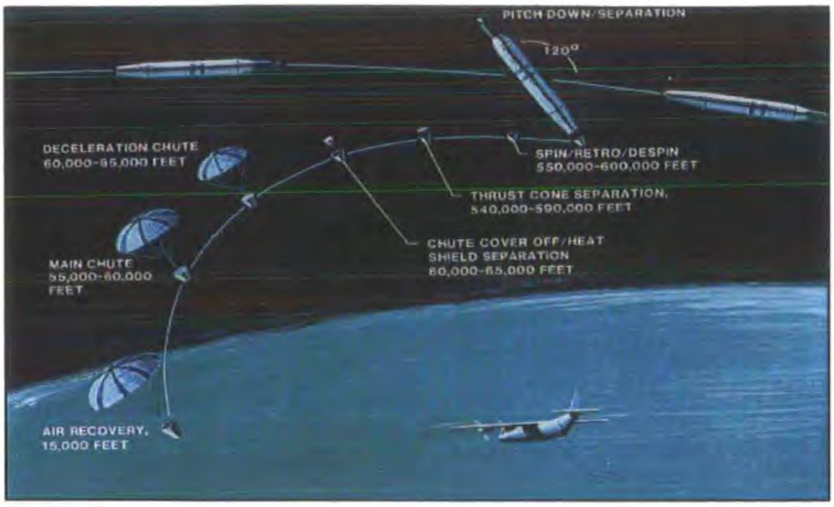


Figure 1: Photography and recovery sequence of Corona satellite system.
Source: http://www.fas.org/spp/military/program/imint/corona.htm, accessed on 06 February 2006.

The programme was code-named Corona, Argon, Mural, Lanyrd, J-1 and J-3. The intelligence community used the designators KH (Key Hole)–1, KH–2, KH–3, KH-4, KH–4A and KH-4B for the Corona systems. The Argon systems were designated

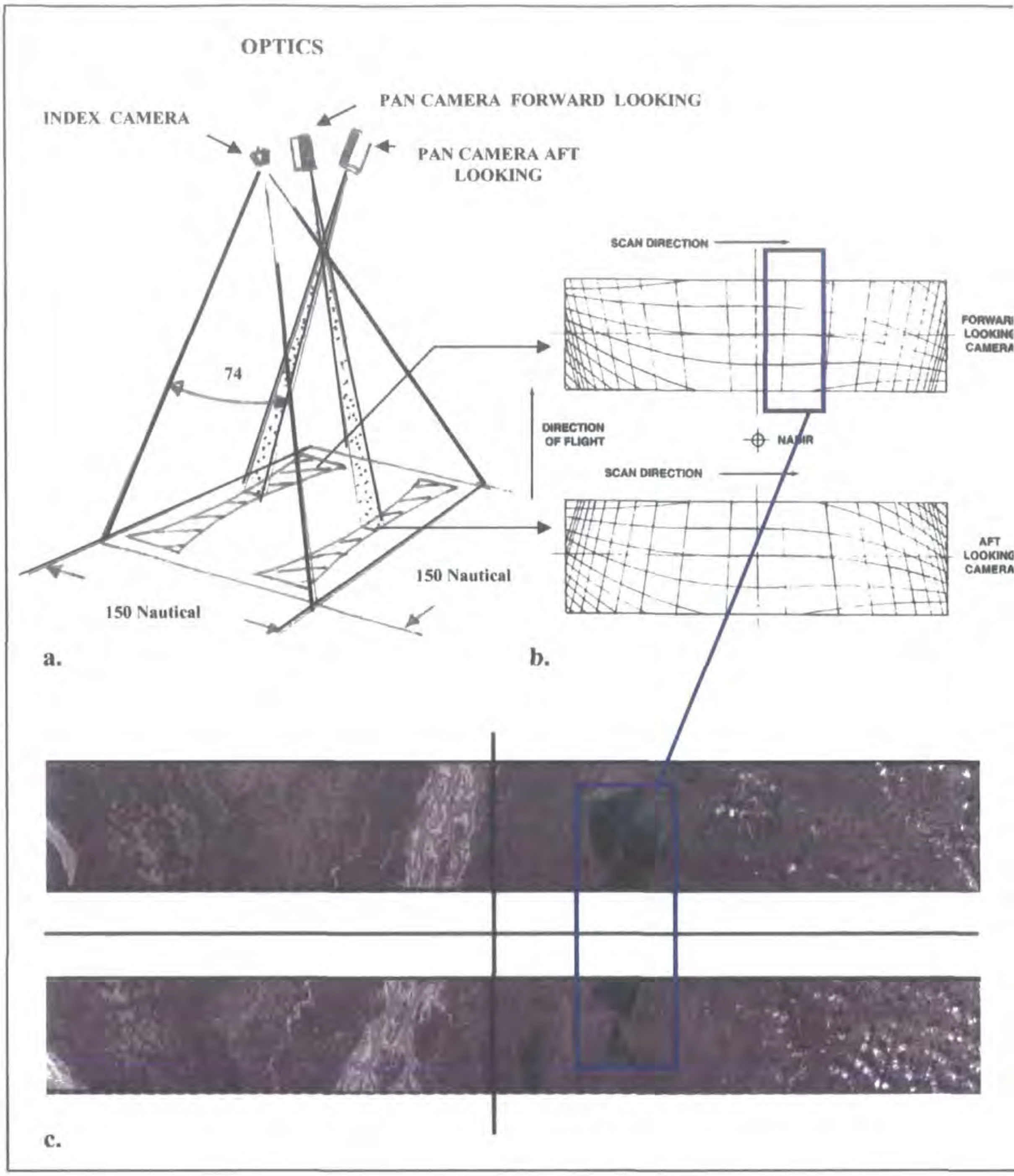


Figure 2: Corona satellite data (1962). a. and b. geometry of earth scanning by camera on board of corona systems. c. film stripes purchased for this research.
Source: http://www.fas.org/spp/military/program/imint/corona.htm, accessed on 06 February 2006.

KH–5 and the Lanyard systems KH–6. The photographs of Corona, Argon and Lanyard systems were declassified by an executive order signed by US President Bill

Clinton in 1995 for the use of scientific and research purposes. The order provides for the declassification of more than 860,000 images of the Earth surface, collected between 1960 and 1972.

Satellite images and aerial photographs are very useful to undertake land cover change studies. Researchers generally prefer to use aerial photographs to map and estimate the natural resources. This research would also have benefited if it were possible to use historical aerial photographs but these could not be accessed from Bangladesh government sources for security reasons. The photographic images of Corona satellite systems were found to be an alternative option to aerial photographs at the changing pattern of forest resources. Rashid (2003) used Corona films for land cover transformation studies and Galiatsatos (2004) the imagery for landscape archaeological research. They both recommended its application as an important source of past records of Earth resources and for features identification.

Two strips of Corona film (scene ID DS009048070DF260 and DS009048070DF261) were selected (figure 2) by searching through the archives of USGS (United States Geological Survey) and were purchased in negative film format in June 2003. Both the films were captured on 24th of November 1962 by KH4 Corona satellite camera system (see table 1 for further attributes). After purchasing the negative image, it was scanned on a Vexcel photogrammetric scanner at 7.5 microns. The image was then geo-referenced with ground control points and transformed to the Bangladesh Traverse Mercator (BTM) projection.

Table 1: Basic properties of Corona film collected for this research.

Dataset Attribute	Attribute Value	Attribute Value
Entity ID	DS009048070DF260	DS009048070DF261
Acquisition Date	24 November 1962	24 November 1962
Camera Resolution	Stereo Medium	Stereo Medium
Camera Type	Forward	Forward
Image Type	Black and White	Black and White
Film Type	70mm Panchromatic	70mm Panchromatic
Polarity	Negative	Negative
Camera Name	KH4	KH4
Ground Resolution	About 8 metres	About 8 metres
Source: http://edcsns17.cr.usgs.gov/EarthExplorer/ http://erg.usgs.gov/isb/pubs/factsheets/fs09096.html		

5.2.1.2 Landsat Images (MSS 1977, TM 1997 and ETM+ 2003)

The Landsat programme is one of the most successful spaceborne Earth observing systems of NASA. Its first mission, Landsat-1 was launched in 1972 and the programme is still continuing to this day. The Landsat Earth resource satellite systems were designed to provide global coverage of the Earth's surface on a regular and predictable basis. Landgrebe (1997) has discussed how the programme became popular with the research community. Four imaging systems, (i) Return Beam Vidicon (RBV), (ii) the Multi-Spectral Scanner (MSS), (iii) Thematic Mapper (TM) and (iv) Enhanced Thematic Mapper (ETM+) have so far been used for scanning the Earth surface from Landsat-1 to Landsat 7 ETM+.

The RBV sensor was the television camera-like instrument that captured image frames of 185km x 185km and was used on Landsat 1, 2 and 3 with different transmission filters (blue, red, near infra-red) with a spatial resolution of 79 metres. MSS had four wavelength bands (green, red and two near IR) with a thermal band in Landsat 3. The MSS was a mechanical scanning device, where six lines were simultaneously swept through an oscillating mirror, acquiring data by scanning the Earth's surface in strips normal to the satellite's motion through 24 signal detectors.

Table 2: Sensor properties on board with Landsat missions.

Sensors	**Landsats 1-3**	**Landsats 4-5**	**Wavelength (micrometres)**	**Resolution (metres)**
Multispectral Scanner (MSS)	Band 4	Band 1	0.5-0.6	80
	Band 5	Band 2	0.6-0.7	80
	Band 6	Band 3	0.7-0.8	80
	Band 7	Band 4	0.8-1.1	80
Thematic Mapper (TM)	Band 1		0.45-0.52	30
	Band 2		0.52-0.60	30
	Band 3		0.63-0.69	30
	Band 4		0.76-0.90	30
	Band 5		1.55-1.75	30
	Band 6		10.40-12.50	120*
	Band 7		2.08-2.35	30
Enhanced Thematic Mapper Plus (ETM+)	Band 1		0.45-0.52	30
	Band 2		0.53-0.61	30
	Band 3		0.63-0.69	30
	Band 4		0.78-0.90	30
	Band 5		1.55-1.75	30
	Band 6		10.40-12.50	60
	Band 7		2.09-2.35	30
	Band 8		.52-.90	15

Source: http://eros.usgs.gov/products/satellite/band.html

The TM sensor is similar to MSS but with improved spatial, spectral (table 2) and radiometric characteristics. Seven bands are used in TM (blue, green, red, near IR, 2 X mid IR) with 16 scan lines. The IFOV is 30m x 30m (120 x 120m for the thermal band). The TM sensor is included in Landsat 4 and 5. Landsat 6 failed to achieve orbit. Landsat ETM+ was launched in 1999 replicating most of the properties of

Thematic Mapper instruments. A new feature of Landsat ETM+ was to capture a panchromatic band with 15 metre spatial resolution. It also captured a thermal band of 60 metre resolution instead of previous predecessors' 120 metres. Landsat MSS (February 1977), Landsat TM (March 1997), Landsat ETM+ (January 2003) have been used in this studty.

5.2.1.3 ASTER Data (2002)

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is an imaging instrument that is flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). ASTER is used to obtain maps of land surface temperature, emissivity, reflectance and elevation. The EOS platforms are part of NASA's Earth Science Enterprise, whose goal is to obtain a better understanding of the interactions between the biosphere, hydrosphere, lithosphere and atmosphere (Abrams 2000).

An ASTER image of March 2003 was purchased for this research (table 3 describes its properties) and its visible near infra red bands were used. These data are used to assess the value of ASTER in a third world context as it is inexpensive and offers a good number of bands in three different spectral regions.

Table 3: Channel properties of the ASTER instrument.

Subsystem	Band number	Spectral range (microns)	Spatial resolution (m)
VNIR (visible to near infra red)	1	0.52 to 0.60	15
	2	0.63 to 0.69	15
	3A Nadir Looking 3B Backward Looking	0.76 to 0.86	15
SWIR (shortwave infra red)	4	1.6 to 1.7	30
	5	2.145 to 2.185	30
	6	2.185 to 2.225	30
	7	2.235 to 2.285	30
	8	2.295 to 2.365	30
	9	2.36 to 2.43	30
TIR (Thermal infra red)	10	8.125 to 8.475	90
	11	8.475 to 8.825	90
	12	8.925 to 9.275	90
	13	10.25 to 10.95	90
	14	10.95 to 11.65	90

Source : http://edcdaac.usgs.gov/aster/asterdataprod.asp, accessed on 06 February 06.

5.2.1.4 Quickbird Satellite Image (2003)

The Quickbird satellite provides the largest swath width, largest on-board storage and highest spatial resolution of any currently available or planned commercial satellites. The satellite was launched on 18 October 2001 using a Boeing Delta II vehicle and placed at an orbit altitude of 450 kilometres. Table 4 illustrates the characteristics of this sun-synchronous satellite data.

Table 4: Spatial and spectral properties of the Quickbird satellite.

Properties	**Panchromatic (nm)**	**Multispectral (nm)**			
Spectral Characteristics	Black and White	Blue	Green	Red	NIR
	450 to 900	450 to 520	520 to 600	630 to 690	760 to 900
Pixel Resolution*	61 cm to 72 cm (2 to 2.4 feet)	2.44 to 2.88 meter (8 to 9.4 feet)			
Scene Dimensions	27552 X 27424 pixels	6888 X 6856 pixels			
Image Bits/Pixel	8 or 16 Bits				
Revisit Time	1 – 3.5 days depending on latitude				
Equator Crossing Time	10 :30 am (descending node)				

Source : http://www.digitalglobe.com/product/basic_imagery.shtml, accessed on 06 February 2006.

Most of the research work undertaken on remote sensing of tropical forestry has used low to medium resolution sensor data such as AVHRR and Landsat. These sometimes impede understanding of the complexities and dynamics at the field level. Fine spatial resolution Quickbird satellite showed greater promise in assessing forest resources in Bangladesh. An image, dated 19 October 2003, covering 64 (8 x 8) kms was acquired for the study area. Geo-referencing was a difficult task for this high resolution image. It was carefully done using Landsat TM 1997 data to transfer its projection parameters from UTM to BTM (Bangladesh Transverse Mercator).

5.2.1.5 IRS-LISS III (2005)

The first IRS satellite of its series IRS-1A was launched in 1988, followed by IRS-1B, launched in 1991. Both of these satellites used Russian Vostok boosters for their placement in orbit. The IRS-1A failed in 1992 but 1B continued to operate until 1999. IRS-1C and IRS-1D were successfully launched in 1995 and 1997 respectively. Both the IRS-1C and 1D produce 5.8 metre panchromatic (0.50 to 0.75 μm, black and white) imagery, which is re-sampled to five metre pixel detail. These two satellites are also equipped with two band Wide Field Sensors (WiFS) that cover a 774 square kilometres (481 square miles) area in a single image as well as LISS-3, which produces a four band (0.52-0.59, 0.62-0.68, 0.77-0.86 and 1.55-1.70 μm) multispectral image with 23.5 metre spatial resolution. A multispectral scene of LISS-3 on board IRS-1D (January 2005) was collected as the most up-to-date imagery for this research.

5.2.2 Vector database

Although the research was carried out mainly with the support of remotely sensed data, some vector based operations were also carried out to facilitate the work. Using vector data on physical determinants like distribution of communication networks/infrastructures, administrative boundaries were found relevant in relation to the image processing results. Most of the datasets used in this research were collected from the LGED (Local Government Engineering Department), Bangladesh.

5.2.3 Field Data

5.2.3.1 Forest Biophysical Variables

Data on forest variables like diameter at breast height, tree height and tree species were recorded (using a metre tape and clinometer) for sample plots in the field. Variables like basal area, wood volume, tree density were calculated later in the laboratory. These datasets helped to develop a relationship with spectral information of remote sensing data that further facilitated the generation of model predictions. Forest field variable information also assisted in the development of signature classes for supervised classification. The sampling methods and data capturing techniques are expanded in chapter three.

5.2.3.2 GPS Data

The aim of a field survey is to acquire good quality sample data on forest variables that are representative of the general forest structure, stem density and other forest variables. In this regard, a GPS (Global Positioning System) survey is fundamental. Sample plots were identified for their latitude and longitude values. The measurements of the central point of the plot were considered as plot location. A Garmin hand-held eTrex 12 channel GPS with +/-15 metre accuracy was used for the purpose. These UTM GPS readings were projected to BTM (table 5) projection before use. The locational values (the ground control points) collected were also used for correcting the geometrical errors inherent in the raw image data.

5.3 Remote Sensing Methods

It is stated in the introductory chapters that the study adopts remote sensing and social science techniques to assess the deciduous forest resources of Bangladesh. The flow diagram (presented in chapter 6) illustrates the method adopted for this study. The methods are mainly divided in three major parts, pre-fieldwork phase, data collection phase (fieldwork stage) and data analysis phase (post-fieldwork stage).

5.3.1. Pre-fieldwork Phase

5.3.1.1. Review of Pertaining Literature

Literature relating to the application of remote sensing techniques in forestry was reviewed that helped to formulate the approach to address the research problem. Based on the survey, research objectives were specified, research questions were developed and methods were selected.

5.3.1.2. Image Acquisition and Sub-setting of Image

Based on the objectives of the research, different image data were acquired (please see chapter 2 for their properties) from different sources. Imagery was clipped according to the desired spatial extents. In this case, three different types of spatial windows were used to subset the image as,

(i) spatial window that is equivalent to a Quickbird image scene,

(ii) spatial window equivalent to thana administration boundary (i.e. Madhupur thana) and

(iii) spatial window covering the upper part of Madhupur tract boundary (the geomorphic unit).

5.3.1.3 Image Geometric Correction

Geometric correction relates the image coordinate system to a specific map coordinate system (Bakker 2001) and is required to remove or reduce the effects of systematic random distortions present in the remote sensing data attributed from variations in sensor system attitude and altitude (Rogan 2004). Stow (1999) asserts that per-pixel registration of multi-temporal remote sensing data is essential for change detection since the mis-registration may lead to an over estimation of actual land cover change. It also needs to be assured that the change that is identified is accurate and not an artefact of an image processing procedure (Rogan 2004). Accurate reference maps or image or GPS data may be used for this rectification (Kardoulas *et* al. 1996). Geometric registration errors between two images is expressed in terms of an acceptable total Root Mean Square Error (RMSE), which represents a measure of deviation of corrected GCP coordinate values from the original reference GCPs used to develop the correction model. Several authors recommended a maximum tolerable RMSE value of <0.5 pixels (Jensen 1996), but others have identified acceptable RMSE values ranging from >0.2 pixels to <0.1 pixels, depending on the type of change being investigated (Townshend *et* al. 1992).

Geometric correction involves two steps: (i) georeferencing and (ii) geocoding. Georeferencing is a process to link an image to a map projection using geometric transformation. Geo-coding is used to correct row and column geometry of an image with respect to a geometrically correct coordinate system (Bekker et. al. 2001). In this study, all the images were geo-corrected (image to image transformation) in respect to Landsat TM 1997 image (considering it as the master image). First order polynomial

Table 5: BTM projection attributes (a), RMSE table for image geo correction (b).

Attribute Heads	Attribute Values
Projection Name	Bangladesh Transverse Mercator
Unit	Metre
Datum	Everest_Bangladesh
Prime Meridian	Greenwich
False Easting	500000
False Northing	-2000000
Base Projection	Transverse Mercator
Central Meridian	90.00
Central Parallel	0.00
Scale Factor	0.9996

a.

Images (geo-referenced in respect to Landsat TM 1997)	Control Point Error (average)		RMSE
	X	Y	
IRS LISS-III 2005	0.1947	0.1702	0.2586
Landsat ETM+ 2003	0.2675	0.2605	0.3733
ASTER 2002	0.3169	0.2671	0.4145
Landsat TM 1991	0.2832	0.4702	0.5489
Corona 1962	0.2084	0.4859	0.5287

b.

transformation was used in every case of image geo-referencing. The root mean square errors (RMSE) are around 0.5 pixels in all the cases (table 5). The images were re-sampled (geo-coded) according to its original corresponding pixel size (i.e. 30 meter for Landsat images, 15 meter for ASTER, 24 meter for IRS LISS-III etc.) using the nearest neighbour interpolation method because this method transfers DN of nearest pixels without altering this value. Although some authors argues about its merits because one pixel may represent spatial average of spectral signatures from two or more surface categories (Schowengerdt 1996). Erdas Imagine software (version 8.7) was used for this purpose.

5.3.2. Class Legends for Classification Schemes

It is mentioned before that Bangladesh forest department does not classify forests in terms of quality. But for remote sensing analysis we need to consider thematic classes. Sections below describe different classes based on forest properties on which the class legends are based.

Closed Canopy Forest: The mature, intact forests are classified as closed canopy forest in the classification schemes. Trees are mature and large (mean dbh is >30cm and tree height >15 m), canopy closure is compact in this class. Most of the trees in this category are *Shorea robusta* species, locally called *sal tree.* The forest was dominated with these large trees in the past but now only left in areas close to local forest offices. Undergrowth is characterised with small bush and shrubs. In satellite data it is pictured as dark (see table 4).

Open Canopy Forest: Open canopy forests are those which are relatively low in density. Tree height <15 m and dbh is <30 cm in this forest class. The canopy closures of these areas become open as mature and large *Shorea robusta* trees were removed from this type of forests. The open canopy forests are dominated by *Shorea robusta* trees species with a mixture of other species. The trees are sometimes broken. Dry grounds, sometimes with grass and bush/shrubs, are exposed. Satellite imagary distinctly shows these areas as seperable from other classes.

Degraded Forest: Degraded forests are those from which most of the trees are removed but still there are some remnants. This types of forests are sometimes dominated by the coppice generated *Shorea robusta* tree saplings. These bright green saplings/young trees in this class are easily visualized in the satellite image and can be separated from other types of forests. However, it is sometimes difficult to distinct this class from open canopy forest.

Cleared out Area: Cleared out areas are completely barren (tree less). The dry soil, undergrowth, grass (sometimes with dry grass), coppice generated sal seedlings all contribute to produce very bright tones on the satellite images.

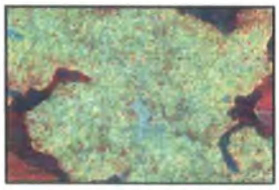
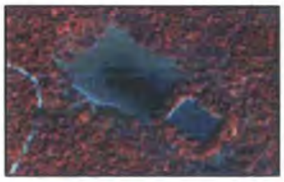
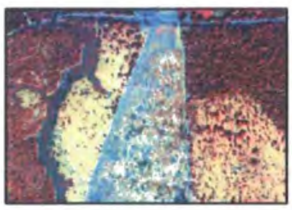
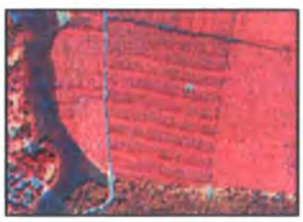
Agro-forestry: The plantations which happened through social forestry programmes are considered as the agro-forestry class. The tree species are different (mainly *Acacia magnun*) from the sal tree. Sometimes, agro-forestry plots are mixed with vegetable farming.

Table 6 describes the properties of forest classes, while table 7 gives an over view about the non-forest classification schemes.

Table 6: Illustration of forest classes.

Class	Reference photograph	Quickbird sample clip	Basic characteristics (average)
Closed Canopy Forest			- dbh >30 cm - height >15 m - Dark tone in satellite image. - closed canopy cover - vibrant undergrowth
Open Canopy Forest			- dbh <30 cm - height <15 m - distinct gap between trees - coppice seedling present in the undergrowth
Degraded Forest/Shorea robusta tree Saplings			- irregular tree distribution - broken, unhealthy trees - dead and dry undergrowth
Cleared-out Area			- exposed soil - trees absent - grass/bush present
Agro-forest			- mixed species (but mainly Acacia magnum) - vegetable garden as undergrowth

Table 7: Illustration of non-forest classes.

Class	Reference photograph	Quickbird sample clip	Basic characteristics
Bare land			- exposed - dry hillocks - light tone
Water/ LowLand	 	 	- man made lakes/ponds - naturally occurring silted up creeks, now cultivated with paddy - human settlements near by
Grassland			- exposed grassfield in the blank areas. - dry soil condition - some areas with dry grass
Agriculture			- agricultural crops in cleared out areas - light tone

5.4 Determination of Variables to be Measured

The literature survey helped to determine what variables were to be measured in the field (Franklin 1986, Donoghue 2002, Phur and Donoghue *et* al. 2000, Olsson 1994).

The authors suggested estimating standard variables namely diameter at breast height (dbh), stand height, species and tree position in the field to calculate basal area and stand volume in the laboratory. In this study dbh, and tree heights are measured, number of trees are counted in the study plot and species diversity and undergrowths are observed. Age was determined by consultation with the field level forest personnel. GPS, Spiegel Relaskop, Suunto-Clinometer, measuring tapes were used during the field investigation. The areas were also extensively photographed.

5.5. Delineation of Plot Boundaries

Satellite images, maps and local topographic maps were used to locate the position of the plots in the forest and GPS readings were then used to ascertain the precise plot locations. Once plots were identified, the area was demarcated and measurements taken.

5.6. Sampling Design, Ground Survey and Validation

The sampling design is determined by the nature of the sampling units used, their distribution over the forest area, as well as the procedures for taking measurements and analysing the results. The specification for each of these elements can be varied to yield the desired precision at a minimum specified cost (Husch *et* al. 2003). Designs for sampling the areas where forests are heterogeneous are usually more complex than simple random sampling. Therefore, the division of population into homogenous sub-populations underlies idea of stratified random sampling. It reduces the variability within the stratum, which ultimately helps to minimize bias (Moore and McCabe 2002, de Gier 2003).

In this study, a ground survey of 49 forest plots (figure 3) was carried out in the study area. The sample plots are selected in such a way that all the forest management classes are represented. The sample plots are also widely distributed across the study area.

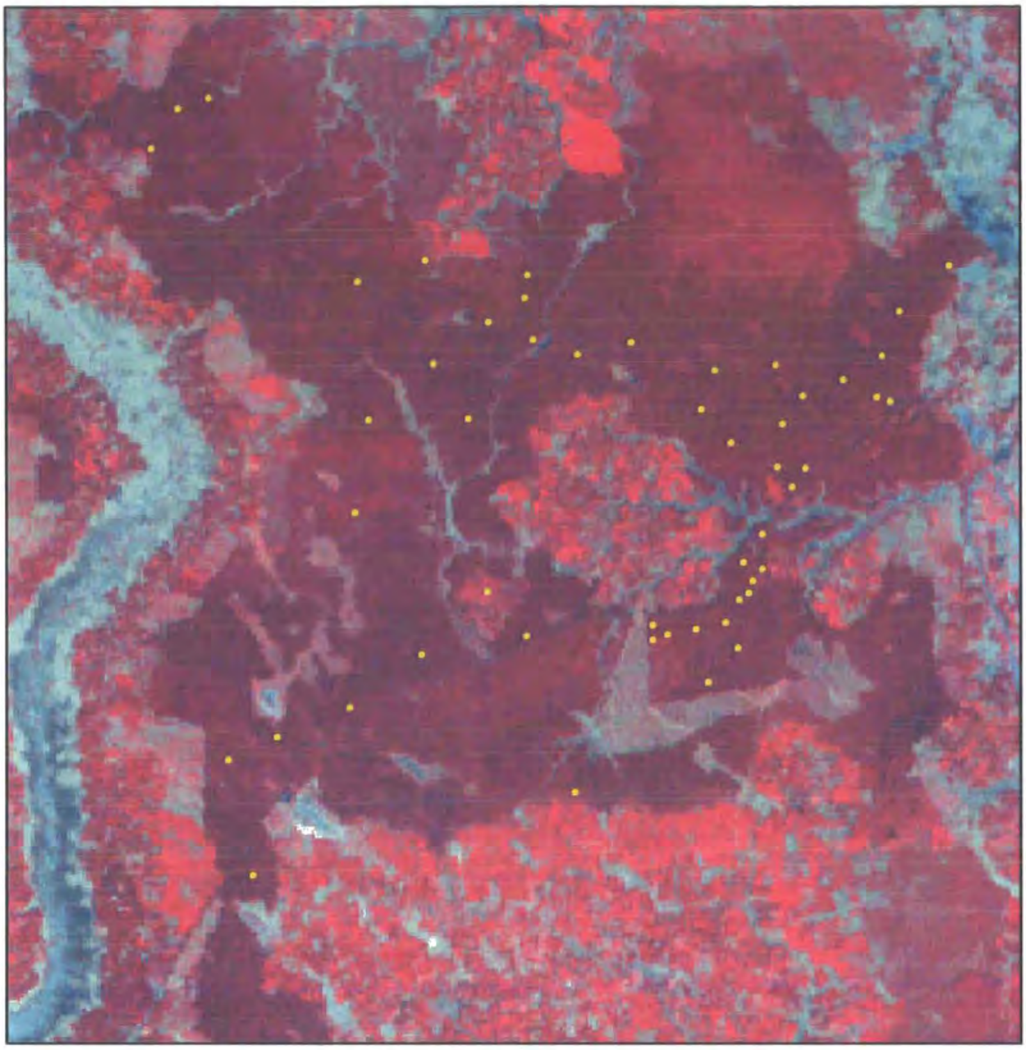


Figure 3: Distribution of sample plots in Landsat ETM+ 2003 image.

First an unsupervised classification was carried out to help identify the major forest classes (the first stratum). Some bigger plots (10 X 10 meters) were taken from these classes which formed the first phase plots. Sub plots (at 5 X 5 metre square plots) were picked up from the first stratum to get the second phase plots. This two phase selection method (Gjertsen, 1991) has been adopted because the forest is heterogeneous, heavily dissected by legal and illegal human interventions and stocked with different types of tree species that have been recently planted by the forest department as a mechanism for coping with rapid deforestation in the area. Consequently, careful attention was paid while selecting the sample sites so that they would represent the forest structure information for all classes. The forest department does not maintain any permanent test plot in the forest, even there is a lack of a compartment-wise forest map available for forest research. Bangladesh forest department generally uses 1:30,000 aerial photographs to delineate the stands for wood extraction or research purposes. The delineated photographs serve as the field maps and help the forest officials to locate the stands in the forest. This plot based information/knowledge was used to help generate forest classifications and for accuracy assessment. In addition, local elderly people and foresters were widely consulted for past information about the occurrence of forests in the area. This plot based information has been to help guide a supervised classification.

5.7. Observation of Sample Plots

Careful observation is required to know the vegetation climax in a tropical forest. The fundamental difference between this type of forest and temperate or upper latitude forest landscapes is that tropical forests are very rich in plant species. Besides, anthropogenic disturbances are also very widespread in tropical forests that drive the researcher to undertake a thorough observation before applying any remote sensing technique to make any inference. Therefore, a detailed observation was undertaken during the field trip to record the species pattern in the sample plots.

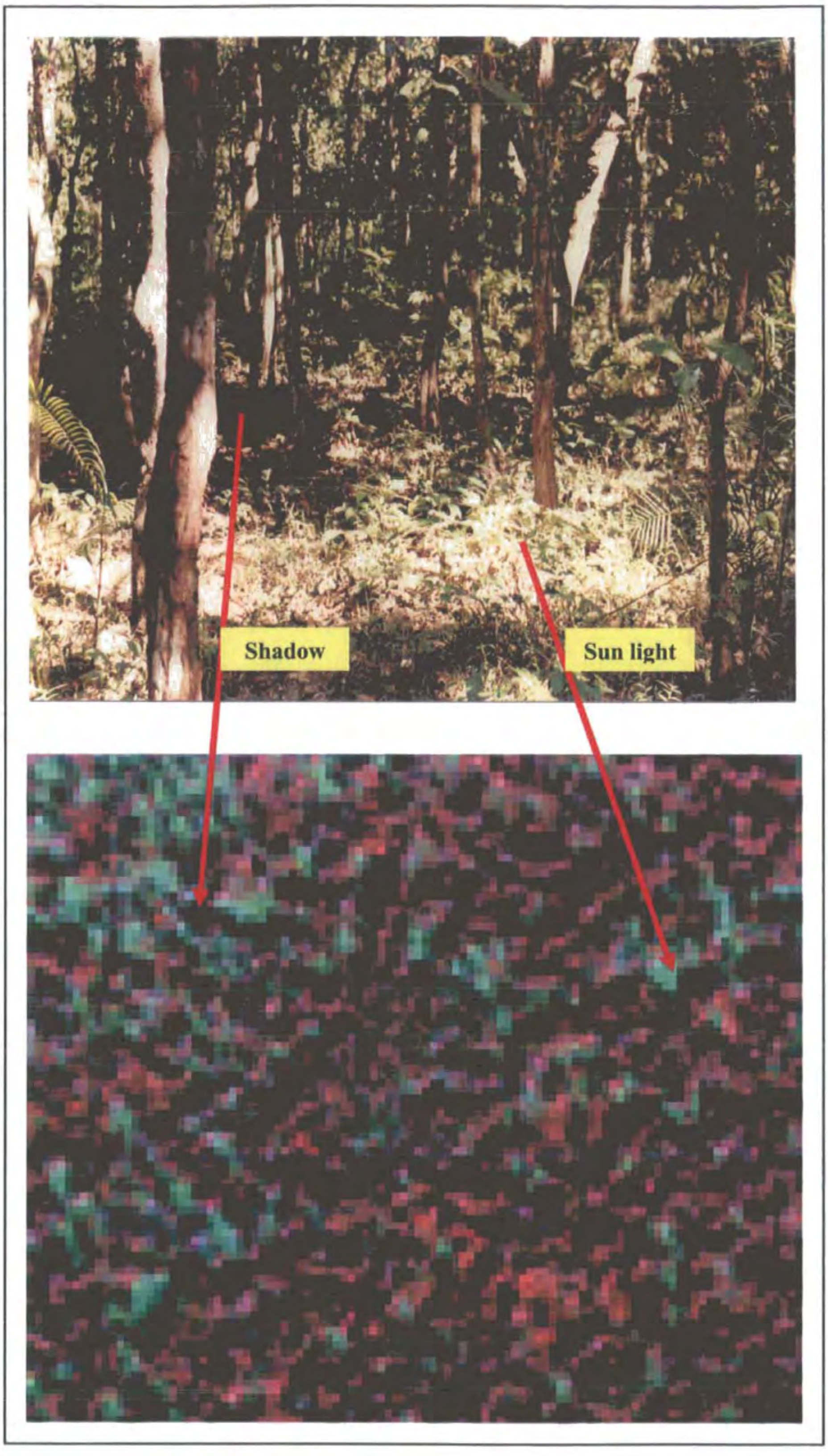


Figure 4: Multi-spectral Quickbird image (2.4 to 2.5 meter spatial resolution, at 12 degree off nadir) depicts understorey vegetation, shadow and sun light

The characteristics of the undergrowth were recorded for those plots, as it is very important to do any analysis using high spatial resolution image data like Quickbird image. The fine spatial resolution allows the sensor to receive signals from both canopy and the undergrowth through canopy gaps, means recorded spectral information may not always represent the canopy reflectance or the pixels may represent a mixed reflectance of canopy, understorey and shadow (Nilsson 2005). In the relatively coarse spatial resolution Landsat ETM+ imagery, this mixed spectral response will be hidden at the scale of 30 X 30 metre pixels.

Figure 4 strongly suggests that the multi-spectral Quickbird data appears to show the ground vegetation, sun lit and shadowed ground through the canopy. Thus the analysis of image based on pixels may not always represent the correct object even though multi-spectral remote sensing imagery is widely used for land cover mapping (Asner 2005, Tuominen 2005).

5.8. Extracting Reflectance Data from Survey Plots

The characteristics of the area or neighbourhood over which computer calculations are made in remote sensing mapping applications are important in achieving reliable, repeatable, and accurate results (Dillworth *et* al.1994). Digital numbers (DNs) represent reflectance in discrete spectral band passes. The DNs were extracted from Quickbird and Landsat ETM+ satellite data for this study. Deriving digital numbers that represent the characteristics of actual ground locations is important for remote sensing mapping applications or to assess the stand structural properties. Digital numbers are extracted using windows of different spatial extent as described by Jensen (1986), Woodcock and Strahler (1987). Spatial windows are the squares or rectangular pixel arrays (figure 5). Dillworth, *et* al. (1994) mentioned that the dimensions or the size of the window that are to be used to extract spectral

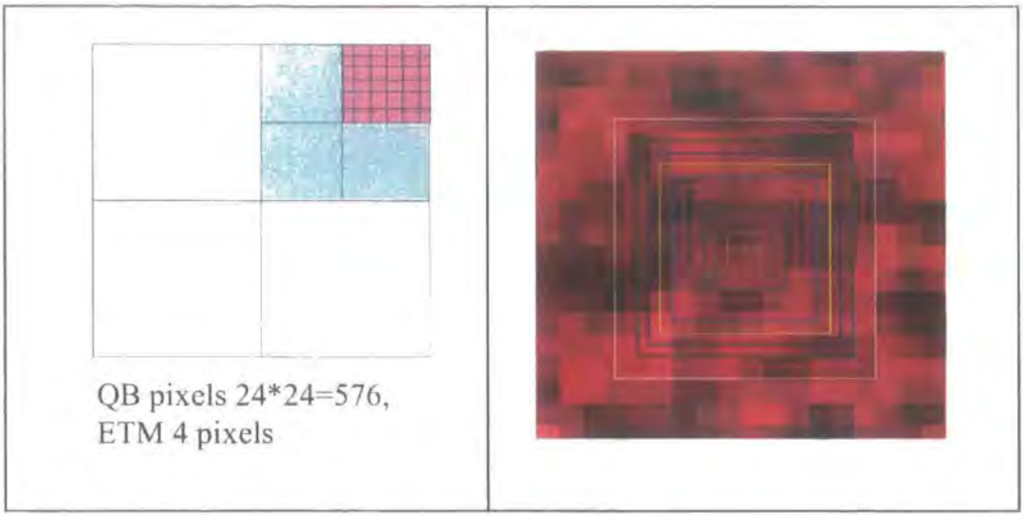


Figure 5. Window that used to maintain same spatial extent to extract pixels from different images.

information is mainly fixed by the researcher for applying equally across a larger geographic region. Ahern (1988) suggested that multiple fixed geometric windows should be assessed for spatial frequency information in a similar land cover mapping exercise. This research used different spatial geometric windows to extract spectral information from image data.

Windows of 17 m X 17 m (7 pixels X 7 pixels), 36 m X 36 m (15 pixels X 15 pixels) and 58 m X 58 m (24 pixels X 24 pixels) were used to extract digital numbers for each stand in each of the reflective Quickbird (multispectral) bands. The Quickbird image positional accuracy was 23 meters and Root Mean Square Error (RMSE) data was 14 meters when it was supplied from its vendor, Digital Globe (www.digitalglobe.com). Besides, the hand held Garmin eTrex GPS used during the field visit gave plot location data with a 5 - 10 meter error. Therefore, 7 pixels X 7 pixels (17 m X 17 m) was considered as the minimum window size to ensure that the ground data plots lay within the sample of satellite reflectance data given the positional inaccuracies. Other window sizes up to 58 m X 58 m (24 pixels X 24 pixels) were also assessed. The size of the window used for pixel extraction from Landsat ETM+ was 4 X 4 (equivalent to Quickbird 24X24). The extracted digital numbers were then averaged. The use of mean digital numbers, instead of the exact pixel believed to correspond to the survey plot, should further help reduce potential errors arising from difficulties of finding the exact location of a survey plot on the image assuming that the plot is located in a homogeneous area of forest (Ahern *et* al. 1991; Puhr and Donoghue 2000).

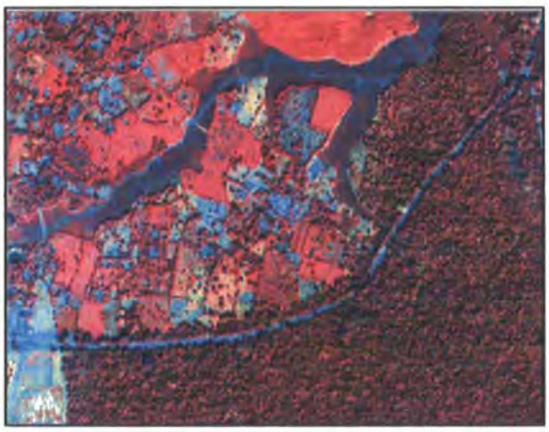


Figure 6. Band combinations 432 of Quickbird satellite image (left) show the corresponding area in the field (right).

5.9. Calculations of Variables

It is mentioned in the previous section that 49 sample plots were surveyed in the field to collect dbh and height measurements. After determining the sample plot with GPS, the area of the plot was marked with coloured ribbon. Each tree (plots are dominated by *Shorea robusta* species) in the sample plot was measured for dbh using diameter tapes. Height for each tree was determined by using clinometer and spigel relascope. These measurements were later used to calculate basal area and volumes were later determined using the volume ratio chart (Appendix 11) for *Shorea robusta* tree species provided by Bangladesh Forest Department.

5.9.1. Calculating Volume Table

In Forest inventory there are four methods of determining tree volumes. They are standard formulae, integration, liquid displacement and graphical method (Husch *et* al. 1972). In the past, tree volume was estimated using the formulae, V = b.h.f., where V is the volume of the tree, b is the cross sectional area at dbh, h is the tree height and f is the factor by which the product of the cross-sectional area and height are multiplied to yield the correct volume (Islam 1993). Today multiple regression analyses are used to select the best suited equations. Bangladesh forest Department followed ten equations to select the best fit see table 1. The best fit regression model is chosen based on the coefficient of determination, mean sum of square error and high F value (Das 1992).

Table 8. Equations for constructing volume table.

No.	Equations for Volume Calculation
1.	$V = b0 + b1\ D$
2.	$V = b0 + b1\ D + b2\ D^2$
3.	$V = b0 + b1\ D^2$
4.	$V = b0 + b1\ D^2H$
5.	$V = b0 + b1\ D^2 + b2\ H + b3\ D^2H$
6.	$V = b0 + b1\ D^2 + b2\ DH + b3\ D^2H$
7.	$\log_e(V) = b0 + b1 \log_e(D)$
8.	$\log_e(V) = b0 + b1 \log_e(D) + b2 \log_e(H)$
9.	$V/D^2 = b0 + b1\ HD^2 + b2/H + b3/D^2$
10.	$V/D^2 = b0 + b1/D^2 + b2/H + b3/D$

Source: Das 1992.

Models were selected for estimation of total volume over bark. The selected equations were transformed for estimation of volume from girth at breast height.

5.10. Basal Area Calculations

The cross sectional area of a tree estimated at breast height is called the tree basal area (Philip 1998). The basal area is generally determined as per hectare (i.e. m^2/hectare). It is usually measured over bark. There are two common ways of estimating stand basal area (Philip 1998):

- from an enumeration of diameters in representative small sample plots,
- from counts of the number of trees subtending an angle equal to or greater than that of a gauge or relascope at representative sampling points in the stand – sometimes refer to as horizontal point sampling.

In this research, total basal area for each plot was calculated by summing individual tree basal areas and the average basal area per hectare was calculated as a proportion of plot area.

The basal area of the stem at breast height was calculated using the following equation,

$$g = \frac{\pi}{40000} \times dbh^2 \qquad \text{..................(1)}$$

Where,

g = basal area of tree (m^2/ha).

dbh = diameter at breast height, m.

5.11. Data Collection

After locating the sample plots using compass and hand-held GPS, dhb and height were measured for all standing and live trees whose dbh are greater than 5 cm using a diameter tape. Gjertsen (2005) considered trees for measurtement in Norway which are dbh>5cm, while McInerney (2005), Watt and Donoghue (2005) considered trees having dbh>7cm. Diameter at breast height (dbh) is defined as the girth at 1.3m above ground level. For tree height measurement all the trees were measured regardless of diameter and then average value is taken as the tree height for a plot though some authors (McInerney 2005) took mean height measurements from representative sample trees for the plot. Watt (2005) mentioned that measuring height of every tree is a departure from a standard inventory where only a sample of tree heights would be measured in each plot. Basal area, volume and tree density were calculated later in the laboratory. Age information, if relevant was obtained from forest officers and local people.

5.12. Spatial units for land cover comparison

Three spatial units, mentioned before, with different size and shape were used for sub-setting images in order to compare land cover change in the study area see figure 4. These are,

(i) Quickbird image equivalent area

(ii) thana administrative boundary equivalent area

(iii) Corona satellite image equivalent area that covers most of the forest cover in the physiographic unit.

The thana boundary polygon is used so that statistics generated can be compared with published data since forest statistics are published in Government reports on a thana basis. The area of interest, equivalent to Quickbird satellite data are used to know the local land use pattern and dynamics in detail. Therefore, areas clipped with the Quickbird satellite image boundary helped to compare the change at a fine spatial scale. The Corona satellite image boundary, covering upper parts of Madhupur tract, was used to assess the overall temporal change in the area at a relatively broader spatial scale see figure 7.

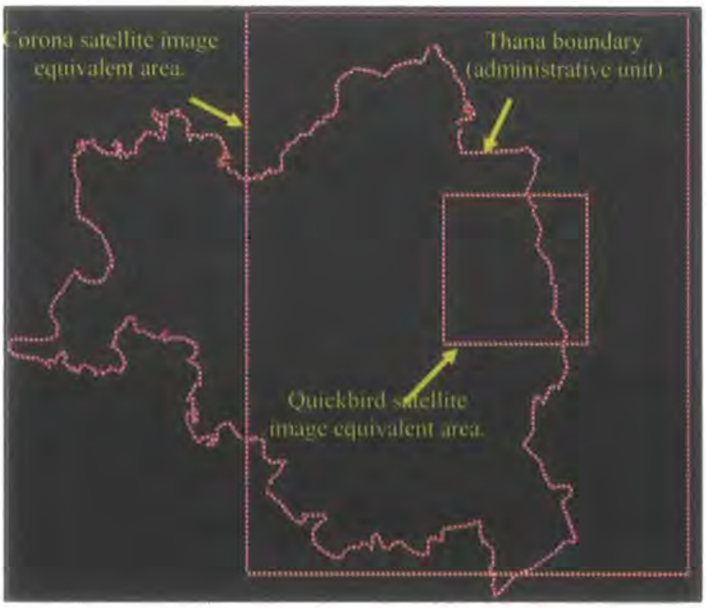


Figure 7: Different spatial units used for comparing land cover change in the study area.

5.13. Collecting Social Variables

The type, quality, shape and spatial extent of the forest biomass and species diversity of a woodland in a third world tropical country like Bangladesh are very much influenced by government policy, planning and the human-induced activities in the area. It is, therefore, necessary to understand the social variables in assessing the forest resources. In this respect, some interviews with planners, foresters and local people were conducted using a semi-structured questionnaire (Appendix 1) and focus group discussion methods. Appendix 3 lists the name of key interviewees. Simple random sampling was employed to select the interviewee households and most of the households were located in the forest and using it for their everyday living. Local elderly village elites gave interesting accounts of past forest distribution. Chapter six illustrates in detail the influence of social variables in relation to forest change in the study area.

Some ancillary data/information from various published sources was used to establish the background of the management and policy options of the sal forest resources of Bangladesh. There are a lot of arguments and disputes from various interest groups on who is responsible for the disappearance of these forests (i.e. government policies or peoples' activities). In addition, there are criticisms (both positive and negative) of donor-aided (World Bank, Asian Development Bank) commercial tree plantation projects replacing the sal (called social forestry programmes) trees by exotic species. This work also assessed the impacts of these projects on natural resources.

5.14. Methods for Remote Sensing Application

Mapping and monitoring temporal changes and quantifying and assessing the structural characteristics of forest resources have been widely recognized as key elements in studies of deforestation. The application of remote sensing, in this regard, has offered an improved method for evaluating the nature and properties of a forest stand. In forest research all over the world remote sensing has been adopted as a state-of-the-art technique. Considerable efforts have been made in Northern Europe using remote sensing to develop techniques for the mapping of forest variables. Tokola, Pitkanen, Partinen and Muinonen (1996), Tomppo (1991), and Katila and Tomppo (2001), have used remote sensing techniques to map the continuous variables, such as basal area and volume, and for cover type in Finland and in the USA (McRoberts 2005, Lopez, Ek and Bauer, 2001). Holmgren and Thuresson (1998) reviewed 30 forest classification studies where remote sensing techniques were used and found a range of 65-85% correctly classified pixels. Donoghue and Watt (2002) collected forest variable data for monitoring the woodland establishment and growth for the UK forest industry where they used medium resolution optical satellite imagery. Foody *et* al. (2001), Apan (1997) undertook forest mapping and change detection analysis in Indonesia and Philippines. Lucas *et* al. (2000a, 2002) focused on forest regeneration in Brazillian Amazon forests.

Both supervised and unsupervised classification techniques were used for mapping and quantifying deciduous forest resources for this study. Post-classification comparison has been used to assess the change in forest cover. Forest bio-physical variables were analysed in relation to spectral response pattern of satellite imagery.

Before applying these techniques, image pre-processing tasks like geo-referencing have been carried out.

5.14.1. Image Classification and Land Cover Change Assessment Methods

Digital satellite data needs to be processed and categorised into classes in a way that are suitable for the user to interpret and analyse. Multispectral image classifications are based upon finding patterns in the spectral response in relation to land cover groups (Wulder 1998). There are two main categories that are used to achieve this outcome called supervised and unsupervised classification techniques. A supervised land classification uses training data input by an analyst which are based upon a training set of pixels at a given location. The first step in the supervised classification (figure 3) is to select training sites for each of the land use categories (Sabins 1997). In this training stage the analyst identifies representative training areas and develops a numerical description of the spectral attributes of each land cover type of interest in the scene (Lillesand and Keifer 2004). The spectral values found at the training sites are then applied to a multispectral classification procedure, such as maximum likelihood function, which enables the portions of the image not directly surveyed to be put into classes based upon similar spectral characteristics to the training areas (Jensen, 1996). In contrast, in unsupervised classification, the software does most of the processing on its own generally resulting in more use categories than the user is interested in. It does not depend on the input of a training data set.

These above mentioned classification techniques, called hard classifiers, sometimes produce uncertainties/mis-classification. Because the method produce one class per pixel, where one pixel may represent an average of different surface categories. Schowengerdt (1996) mentioned that this mixing of signatures arisen from the intrinsic, spatially-mixed nature of most natural land cover categories, the physical continuum that may exist between discrete category labels, resampling for geometric rectification, and by the spatial integration defined by the sensor's point spread function. Soft classifiers (like decision trees and artificial neural networks) have proven superior to conventional classifiers (e.g. maximum likelihood) and have been used in many land cover mapping studies (Huang and Jensen 1997, DeFries and Chan 2000).

In this particular study supervised classification techniques using maximum likelihood algorithm has mainly been used because the methods is able to classify land cover categories based on training areas and field knowledge. Field data and field observation both were useful in defining sample signature files prior to image classification.

Post classification results were used to assess the forest cover change in the study area using multi-temporal, multi spatial resolution satellite data. This post classification technique is considered to be one of the most appropriate and commonly used methods for change detection (Jensen *et* al. 1993, 1996, Dewider 2004). Because the method does not require multi-date image registration and radiometric and atmospheric corrections what are essential in pixel-to-pixel comparison such as image differencing and image rationing (Coppin *et* al. 2004, Lu *et* al. 2004). In post classification method multi temporal satellite images are separately classified into thematic maps, then the thematic maps are compared (Brondizio *et* al. 1994, Foody 2001, Miller *et* al. 1999) for land cover change assessment. In this study satellite images of different dates with different resolution were classified into different classes. Change in closed and open canopy forests are mainly assessed.

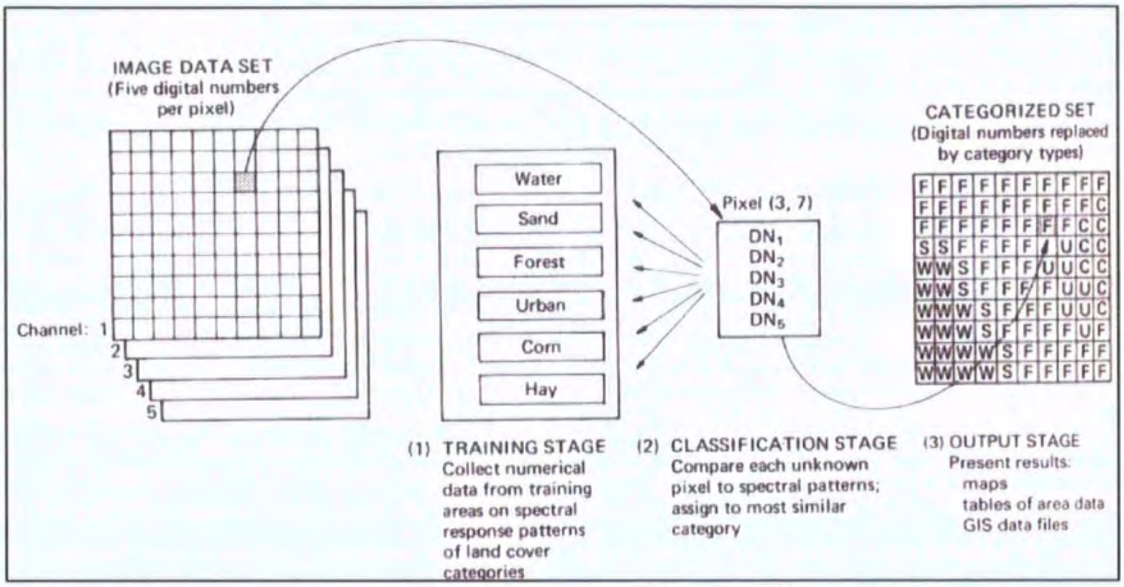


Figure 8: Basic steps of supervised classification. Source: Lillesand and Keifer 2004.

5.14.2. Maximum Likelihood Classifier

Maximum likelihood procedure is one of the most commonly used in supervised classification technique. It is a statistical decision rule that examines the probability of a pixel in relation to each class with assignment of the pixel to the class with the highest probability. This classification method quantitatively evaluates both variance and covariance of the category spectral response patterns when classifying an unknown pixel (Lillesand and Kiefer, 2004). To do this, assumes that the data distribution is normal or Gaussian. Visual image enhancements may be utilized to aid in the interpretation of imagery or for assistance in the creation of training data. Despite careful efforts, there might be confusions in classification results. Therefore, accuracy assessment of the classified images is undertaken prior to the reporting of the results.

5.14.3. Accuracy Assessment of Remote Sensing Results

Remote sensing data provides strong evidence of natural resource occurrence, its characteristics, growth and temporal change. However, there are different sources of error that might effect remote sensing data, specially in cases of tropical forestry research (Foody 1997), that may undermine the results; sometimes the results may be unacceptable (Congalton and Green 1999). In many instances, researchers used comparatively high resolution satellite data like Landsat TM for assessing coarse resolution satellite data like NOAA AVHRR (Achard 2002). Lambin and Ehrlich (1997) mentioned that most of the tropical forest research activities were conducted at broad spatial scales. They stressed that research at a fine spatial scale in tropical countries is necessary to understand the dynamics (including social drivers) of forest change. Lambin *et* al. (2002) in another study emphasized that local knowledge is one of the crucial source for accuracy assessment for small-area studies. Sometimes, researchers face difficulties to carry out accuracy assessment in tropical forests due to its complex mix of vegetation types and landuse patterns (Lucas *et* al. 2000a). Lucas *et* al. (2000a) admitted while characterising Cameroonian tropical forest regeneration that rigorous accuracy assessment could not be done due to reference data limitations. They checked their results with Forest Association Map produced by Cameroon Government and got an overall accuracy of 64.10%. High spatial resolution satellite data like Ikonos, Quickbird, in that regard, provide a new and important source of data for validation and checking. Quickbird satellite data (specially panchromatic imagary), proved extremely useful, if interpreted carefully to assess the accuracy of the classification results of Landsat ETM+ and Quickbird multispectral images. A post classification accuracy assessment was carried out in this study to determine the level of accuracy of classification results derived from Quickbird and Landsat ETM+ satellite data of 2003.. High spatial resolution (0.60 meter at nadir, this dataset is 12 degree off nadir) Quickbird panchromatic satellite image in addition to field observation methods were used for accuracy assessment purposes.

5.14.4. Methods Involved in Accuracy Assessment

Accuracy assessment is a term for comparing the classification results with the real world/true data in order to determine the accuracy of the classification process (Leica Geosystems 2003). In other words, it determines the quality of the information derived from the remotely sensed data (Congalton and Green 1999). It is not realistic to check every pixel in the classification map for accuracy, rather a set of sample pixels are generated to compare with the reference points. Information about reference pixels/points are sometimes gathered from ground surveying (Donoghue and Watt 2005), sometimes compared with published maps/records (Lucas *et* al. 2000a), sometimes with the aid of high spatial resolution satellite data and aerial photographs. It is mentioned earlier that information about reference points are derived from Quickbird panchromatic data in this research. Extensive field survey conducted in 2003 in the area also helped to determine the land cover classes. Points for validation checking were randomly generated (i.e. 255 points for Quickbird classification and 305 for Landsat ETM+ classification) for the accuracy assessment process. A search window is used to derive the class value for a selected pixel. The centre pixel of the search window was selected. In this case, 1024 search windows were used for selecting those 255 and 305 points for Quickbird and Landst ETM+ classification results respectively. Stratified random or equalized random parameters could be set to generate point distribution, but these were not used because some land cover classes represent very small area in the classification scheme. The random points and reference information were then used to generate an error matrix in order to derive class wise and overall accuracy estimates.

5.15. Methods for Analysing Social Variables

Studying *forest resources* and studying *forest degradation* is almost synonymous in the case of Madhupur forest (the following chapters will give accounts about this claim). 'The forest is declining fast'- this notion is established among concerned groups in Bangladesh. The forest department of Bangladesh admitted that they have implemented nine projects (BARC, 1994) in Madhupur sal forests up to now in response to that forest depletion, involving a lot of money. But unfortunately their actions have not worked well and, rather, appear to have caused further forest destruction. The main causes of these failures exist in the fact that the planners do not know the real condition of the resources in terms of structural quality, spatial extent and temporal change. This lack of information leads the authorities/planners to develop and deploy flawed proposals. The second problem rests in conceptualizing the problem. The government is unsure about the appropriate management approach of the forest; whether the resources should go for economic benefits of the country, or for the welfare of the environment, or in support for local livelihoods, or whether resources should be used in a balanced way. The authorities commonly use the term 'sustainability' for forest management without understanding the true meaning and sense of the term. Gani *et* al. (1990a, 1990b), MoEF (1997) outlined the approaches, objectives and mechanism of sal forest rehabilitation in the study area. These government planning reports did not reflect the existing forest resource conditions and distribution and aimed to generate monetary resources, though in truth the forest's the quantity and quality have reduced a low point. There was no indication as well how official corruption (allegedly by forest officers) should be dealt with, as it is a major concern in the area. My research indicates that the political realm of the society mainly shapes the forest and defines where and what type of forest should be developed or not developed. Local people are commonly blamed for forest degradation but it will be shown that government policies, donor aided projects, historical legacies in relation to land ownership disputes, and government land reform are the prime causes of deforestation. In this regard, political ecology as a theoretical framework has been used in this research to understand the complex relations between nature and society, where problems are viewed in a broader context rather than blaming them on proximate and local forces. And this analysis was based on thorough literature review, results derived from questionnaire survey and interview.

5.16. Blending Physical and Human Geography: An Integrated Approach to Assess Deforestation in Bangladesh

This work used established methods of remote sensing to assess the forest condition and different aspects change (spatial and temporal at different scales). Secondly, political ecology has been used to seek out the root causes of environmental breakdown in the study area. The argument for this integration lies in the fact that the environmental problems in the Third World, including Bangladesh, are fundamentally different from those that occur in the developed world. The environmental problems (especially deforestation/forest degradation) in the 'north' is better understood and may be solved using technological solutions based on natural science research experiments (including physical geography) because the immediate anthropogenic causes associated to these problems are less serious compared to those in the 'south'. In the Less Developed Countries for various reasons people are pushed, due to economic reasons, eviction, tenancy disputes, or the lack of alternative coping opportunities, towards over-exploitative behaviour with respect to the environment. On the other hand, environmental crises in most of the Third World countries are social (Blaikie 1985, Blaikie and Brookfield 1993, 1987) and need a holistic approach. Blaikie (1985) in his seminal work 'the political economy of soil erosion in the third world' showed that deforestation is not only physical phenomenon, but is socially rooted. He argued that the activities that cause deforestation are the consequences of the complicated historical, socio-cultural and technocratic organization of that space. It is also a problem of land managers, who undertake duties according to the directions of political, social and economic institutions and attitudes of that time and society. Sometimes, land managers neglect their role to implement their knowledge in forest or land management. The decisions that are supposed to be made by the manager are rather taken by someone else. For instance, as a response to deforestation and forest degradation (please see chapter three and six), the professional foresters in the study area are now undertaking agro-forestry projects, where the supervision of agricultural activities (including land distribution, agricultural tax collection etc.) are becoming his main duties. His professional forestry knowledge is now fostering non-forestry[1] practices. This might be treated as misuse of resources, intellectual capital and frustratingly at a cost of further land degradation, as agro-forestry is not forest according to the definition of forest (FAO 2000). These arguments suggest that we need to look beyond the way we generally

[1] Agro-forestry is counted as a non-forest system when it mainly produces agricultural outputs (See Wunder 1997, cited in Contreras-Hermosilla 2005). In Madhupur, agricultural practice is the prominent activity in the name of agro-forestry.

address deforestation problems. Geographical expertise (based on physical and human geographical knowledge) is valuable to try to understand the deforestation and forest degradation problems as a whole and to suggest alternative measures to cope in a pragmatic way.

The strength of geography as a discipline is rooted in the fact that it is *concerned with understanding the spatial dimensions of environmental and social processes* (White 2002). These two dimensions are traded with distinct approaches of geography (i.e. physical and human geography) with robust methodological tools for assessment. But scholars (Skole 2004, Matthews and Herbert 2004, Thrift 2002) are frustrated to see that the collaboration of physical and human geography approaches is not widespread. My research comes at a time when scholars of the field are urging that unity would show how the discipline (geography) could be dominant in the field of human-environment interface research.

The methods of physical geography are employed in this research, as it has always been a major interest in natural environmental change (Matthews and Herbert 2004) and ecosystems. Remote sensing applications, (in particular in the physical side) have helped to measure environmental processes and to monitor the impacts of negative effects. Human geography (political ecology in particular), on the other hand, aids approaches that focus on people's/society's values, choices, forms and responses, and helps the study of changing economic and political systems with the support of historical geography (Pacione 1987). Figure 8, based on this research methodology, shows that both approaches (remote sensing and political ecology) are based on the core tools (i.e. field methods, quantitative tools, space and time issues, spatial organization and cartography/maps) of geography (National Research Council 1997) and respond on a set of questions necessary for generating useful alternatives. The real strength of this integrative approach lies in the fact that both approaches bear the geographer's spatial perspective and an interest in scales and the specificity of place.

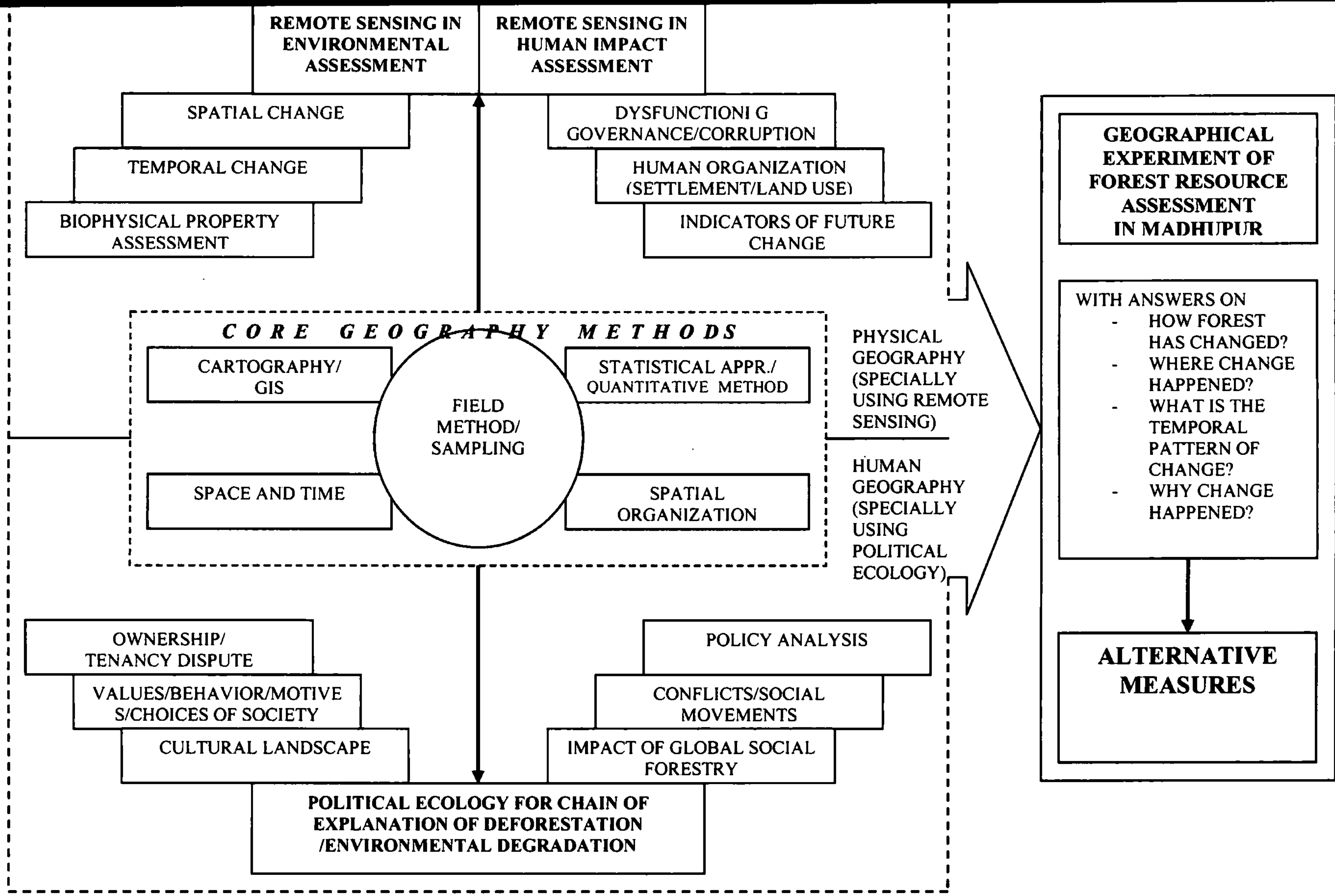


Figure 9: Integration of physical and human geographical methods to address the deforestation problems in Madhupur forest.

5.17. Conclusion

Researchers like Zimmerer and Bassett (2003), McCusker (2003), and Robbins (2001) integrated remote sensing application with political ecological explanations of forest degradation. Robbins (2003) discussed the epistemological challenges in integrating geo-spatial technologies in political ecology. In Bangladesh, this integrated approach is new to the assessment of forest resources. However, the research might has two implications

- *academic significance*
- *operational implications.*

The present study creates an opening for academics and researchers to use modern-day data, methods/approaches in Bangladesh for assessing its forest resources. This technique could be replicated in other forest areas in Bangladesh (i.e. the evergreen forest in the south-east and the mangrove forests in the south-west), which are also suffering from various different problems. In addition, concerned authorities may improve their methodology for proper forest assessment.

Chapter 6
Remote Sensing Results

6.1. Introduction

This chapter presents the results derived from remote sensing analysis. The data and methods used for this chapter have been presented in chapter 4. A combination of supervised and unsupervised classification techniques were used to differentiate forest cover from non-forest landuses using the best available remotely sensed imagery over a forty year period. These data were then used to measure forest cover and map change in its spatial extent.

The second objective is to assess the quality of the remaining forest land using satellite imagery, in particular new fine spatial resolution image data such as Quickbird. The amount of high quality intact forest land cover could easily be overestimated from analysis of low or medium spatial resolution satellite imagery such as AVHRR and Landsat TM / ETM+. Therefore, it is important to evaluate the potential of Quickbird and other fine spatial resolution imagery as an objective and independent method for assessing both the quantity and quality of forest land.

The chapter, does not, intent to develop any new scientific approach to forest assessment, rather it uses established methods of optical remote sensing in order to demonstrate their value for forest assessment in a developing country using objective methods. It is notoriously difficult to establish accurate long-term data on spatial patterns of deforestation in developing countries and so an important part of the study has been compiling image data that can be used to quantify change in the study area.

The remote sensing techniques highlight the physical part, the 'what' and 'where' questions; the results are then used to assess the social components, the 'why' and 'how' questions underlying deforestation and land degradation in central Bangladesh.

6.2. Description of Work Flow

It is mentioned in the earlier sections that remote sensing methods have been used in this study to assess the current condition of the forest resources and to detect temporal changes in the study area. The remote sensing methods involved data collection, image pre-processing through to the image analysis and interpretation phase. Figure 1 shows the workflow of this study. Chapter 2, and 4 discussed about the satellite data used, pre-processing and analysis methods.

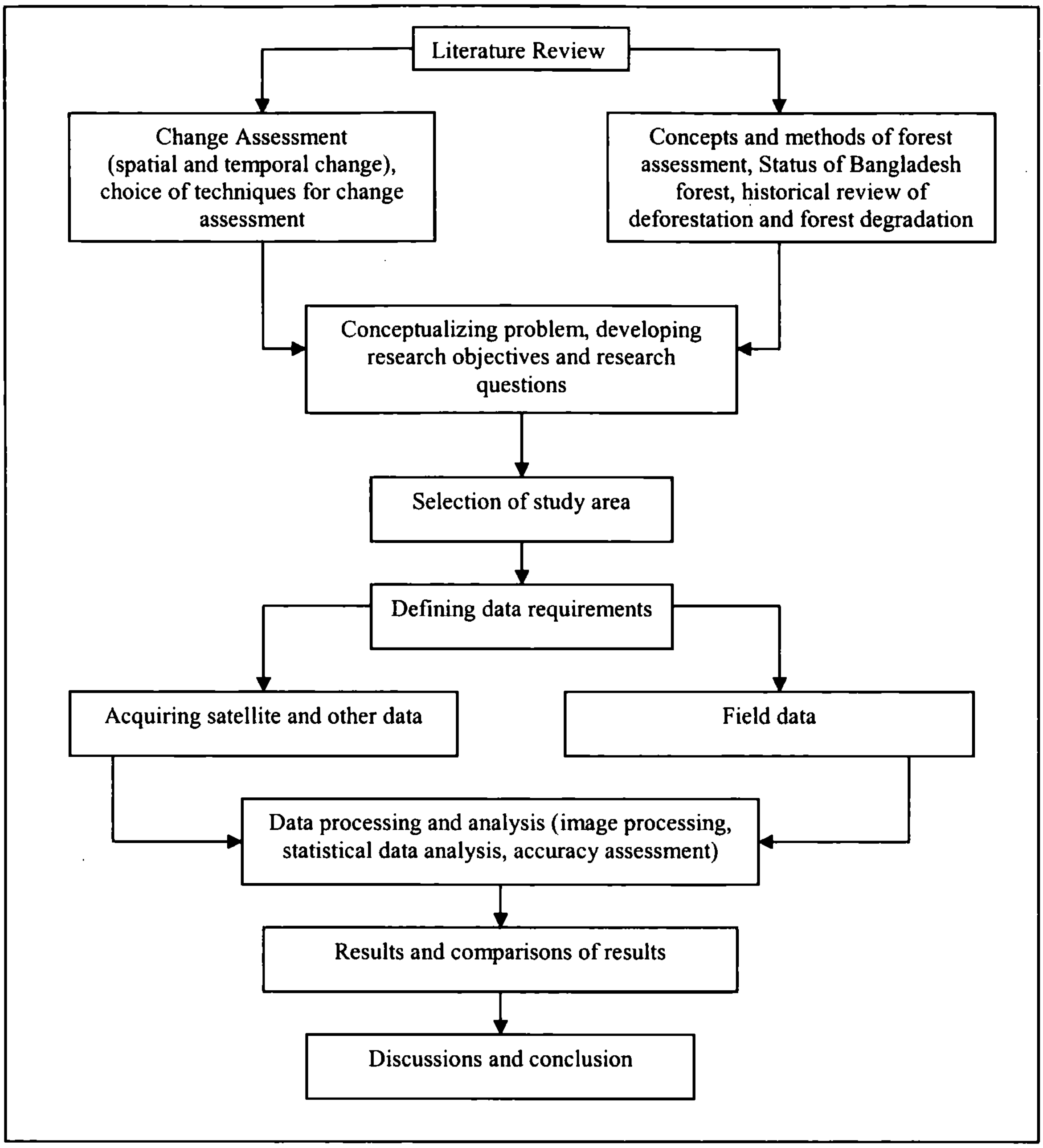


Figure 1: Work flow of remote sensing techniques.

6.3. Inspection of Spectral Signatures

Several satellite images are used to differentiate between forest and non forest land cover in the study area from 1962 to the present day. As it mentioned before, the Corona satellite data from 1962 is the oldest set of data used here to compare the forest cover change. CORONA KH-4 imagery was recorded on high definition specialist photographic film and digitized from a small part of a negative using calibrated photogrammetric scanner. The high quality of the original panchromatic film and its excellent spatial resolution meant that it was easy to identify areas of mature forest cover (that still exist today) on the CORONA imagery. Density slicing was used to establish the appropriate tonal range that best appeared to separates forest from non-forest land cover types. Once established this could be used to produce a simple forest / non-forest map that could be tested against existing patches of forest and verified by consulting the local people during the field visit. Local tribes/people were also consulted to help validate the supervised classification results of other datasets such as Landsat MSS (1977) and Landsat TM (1991 and 1997). But for the classifications of more recently acquired imagery (i.e. ASTER, Landsat ETM+ and Quickbird) it was possible to examine spectral signatures using a statistical separability test. Table 1 shows the Euclidean spectral distance between the means of different signature classes. The distance measure can be used to determine how separate the signatures are from one forest class to another. Bands 2, 3, 4, 5 and 7 for the Landsat ETM+ image and bands 1, 2, 3 and 4 of the Quickbird image were used to determine the separability among eight signature classes. The average Euclidean distance of Landsat ETM+ signature classes is 34, where this value between sal tree seedlings and Bareland and acacia tree is 51. This means that the signatures for forests, barelands and grasslands are spectrally distinct (figure 2, 3). But there is uncertainty in discriminating open forest from a closed forest class. The same results are also evidenced for Quickbird signature classes. To improve the distinctiveness of training classes, field data and field observation were used.

Table 1: Results of separability test.

Average Separability for Landsat ETM+ (2003) Image Signature Classes							
Class Pairs and Corresponding Distance							
Class Pairs	*Euclidian Distance*	*Class Pairs*	*Euclidian Distance*	*Class Pairs*	*Euclidian Distance*	*Class Pairs*	*Euclidian Distance*
1:2	9	2:3	51	3:5	41	4:8	32
1:3	54	2:4	35	3:6	67	5:6	29
1:4	42	2:5	24	3:7	59	5:7	31
1:5	19	2:6	29	3:8	56	5:8	35
1:6	22	2:7	8	4:5	48	6:7	28
1:7	12	2:8	13	4:6	52	6:8	38
1:8	21	3:4	54	4:7	37	7:8	11
Bands used 2,3,4,5,7. Average distance 34. Minimum distance 8.							
Average Separability for Quickbird (2003) Image Signature Classes							
Class Pairs and Corresponding Distance							
Class Pairs	*Euclidian Distance*	*Class Pairs*	*Euclidian Distance*	*Class Pairs*	*Euclidian Distance*	*Class Pairs*	*Euclidian Distance*
1:2	202	2:3	36	3:5	20	4:8	40
1:3	52	2:4	716	3:6	53	5:6	146
1:4	518	2:5	145	3:7	161	5:7	50
1:5	71	2:6	278	3:8	147	5:8	246
1:6	77	2:7	97	4:5	586	6:7	193
1:7	116	2:8	380	4:6	441	6:8	102
1:8	179	3:4	480	4:7	634	7:8	294
Bands used 1,2,3,4. Average distance 252. Minimum distance 50.							
Signature Classes: 1. Sal Seedling 2. Bareland and Acacia 3. Grassland 4. Water 5. Agriculture/Garden 6. Agro-forest 7. Open canopy forest 8. Closed canopy forest.							

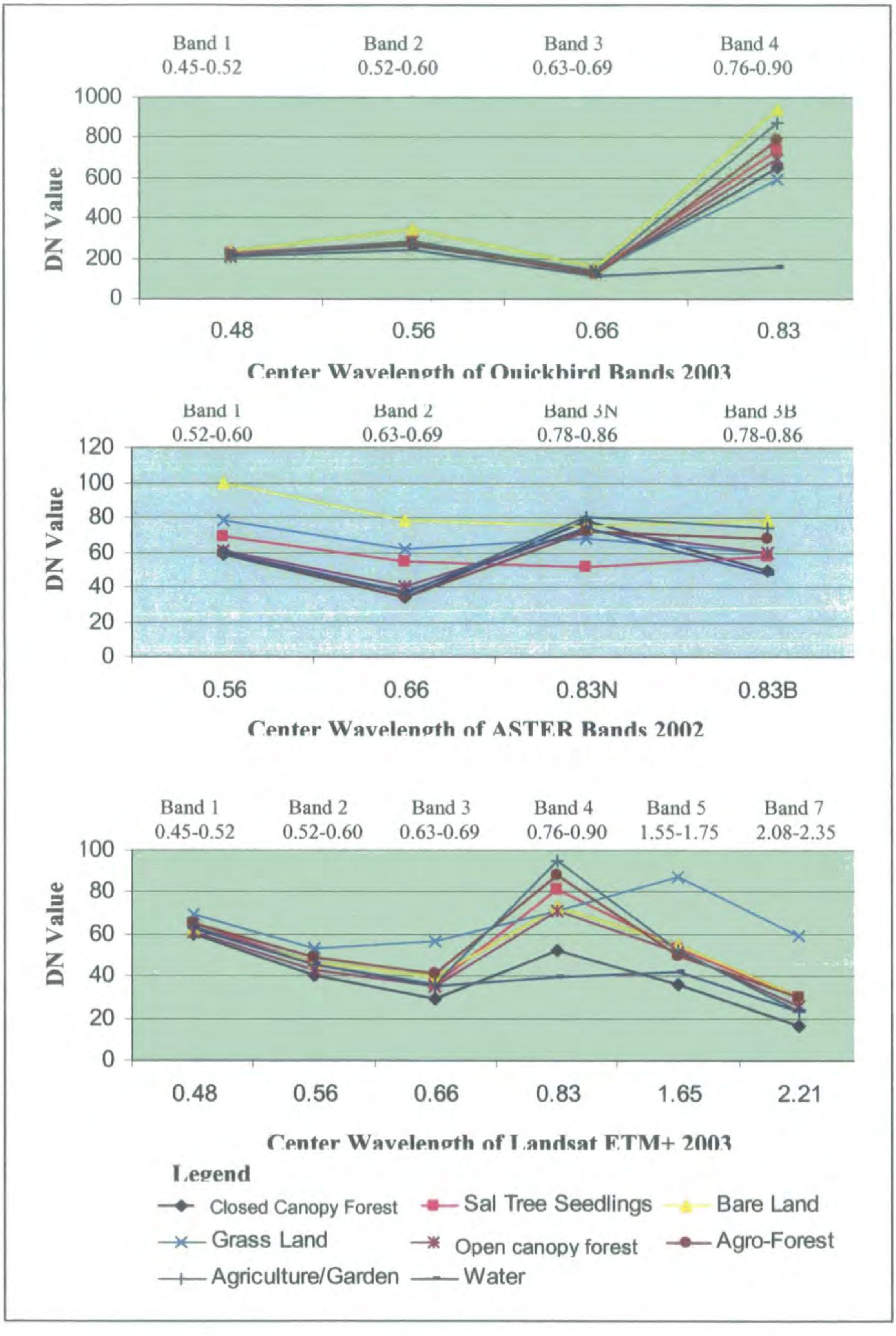
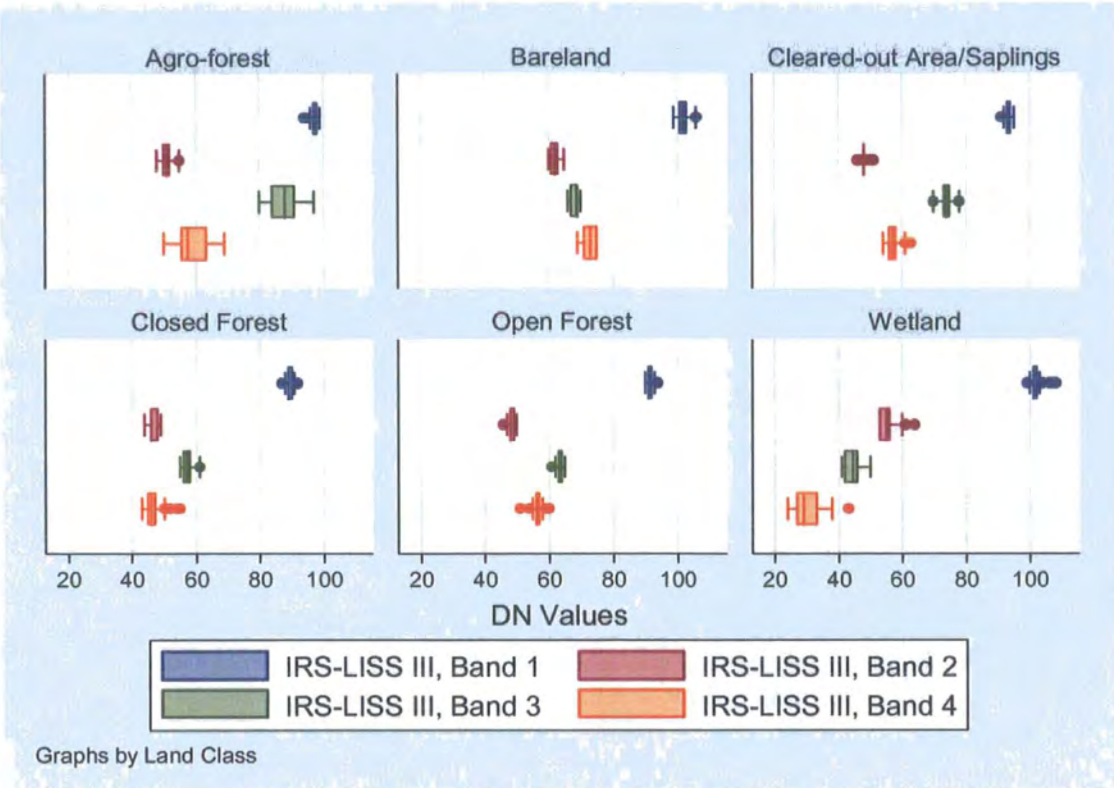


Figure 2: Spectral signature graph.



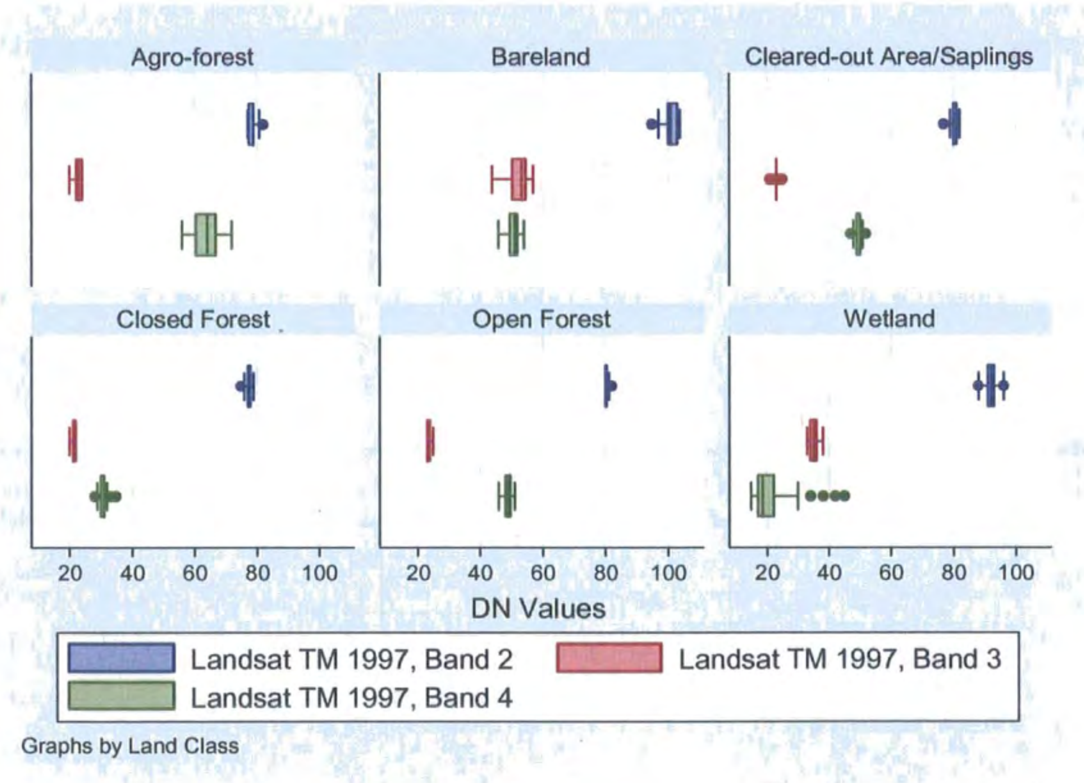
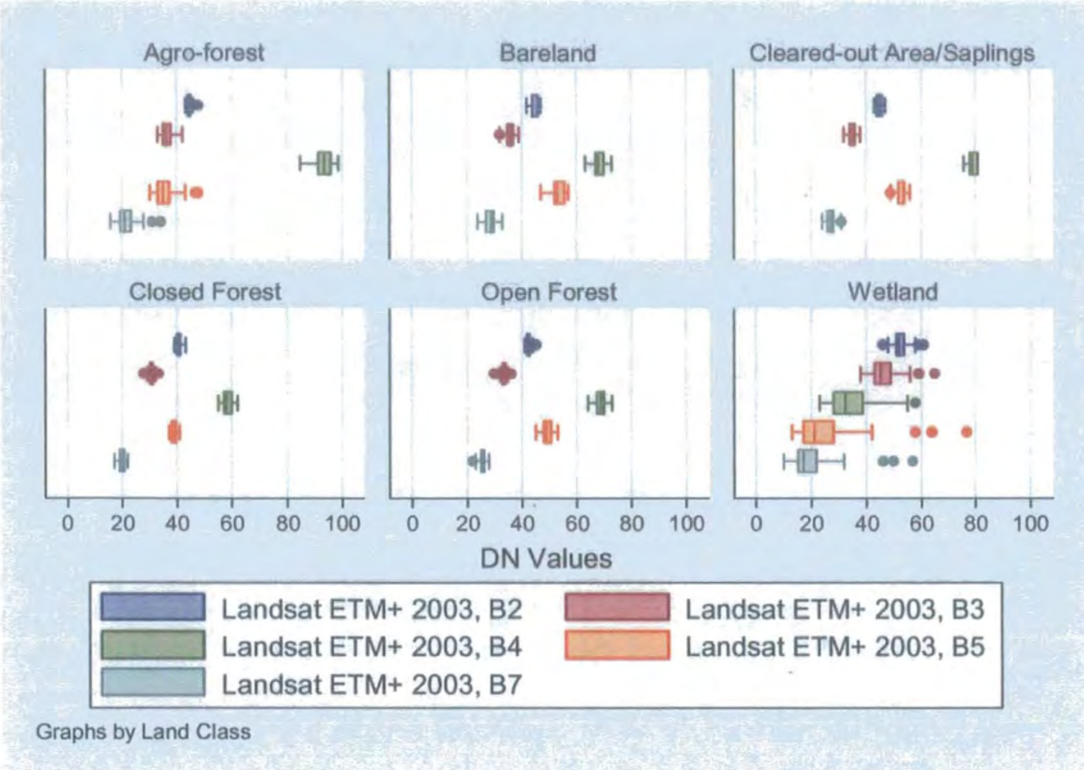


Figure 3a: Spectral response patterns of different bands of IRS-LISS III 2005 and Landsat TM 1997 for different land classes (data extracted from sample plots).



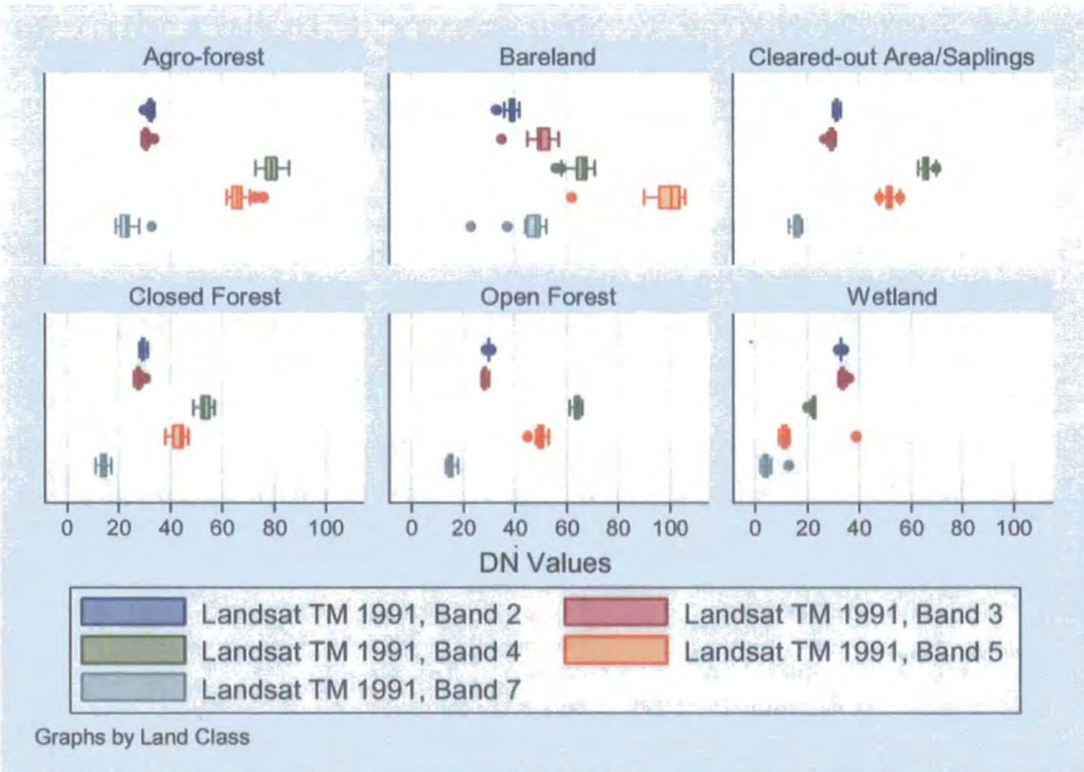


Figure 3b: Spectral response patterns of different bands of Landsat ETM+ 2003 and Landsat TM 1991 for different land classes (data extracted from sample plots).

The results are presented for the area equivalent to the Quickbird image scene so that a comparison between the historical imagery and the new finer spatial resolution data can b made. The area covered in each scene is about 6682 hectares see figure 4, table 2. Corona image (1962), Landsat MSS (1977) and TM (1991) are classified into broad land cover classes but th latter datasets are classified in more detail. It is suggested from the classification that most of th area was under forest in 1962 estimated as 3826 hectares that included both the closed and ope canopy forests and the has reduced dramatically through time see table 9. A sharp change is seen

Table 2: Land cover types in different sensor systems (units in hectares).

Land Cover Types	Corona Image 1962	Landsat MSS 1977	Landsat TM 1991	Landsat TM 1997	ASTER 2002	Landsat ETM+ 2003	Quickbird 2003
Closed canopy Forest	3826	3573	2102	1801	560	1270	594
Open canopy Forest			767	947	764	755	1563
Cleared-out Area		-	-	166	981	236	859
Agriculture/Gardens		838	1044	953	1377	1407	610
Bareland/Grassland		-	261	350	1161	1089	1590
Wetlands		2047	2234	1901	1480	995	1371
Others	2856	224	274	559	358	930	95

from 1977 (Landsat MSS) to 1991 (Landsat TM). The apparent deforestation over this tim period mainly coincided with the government policy of establishing a security installation (a airforce firing ground) in the middle part of the forest by clearing out a large area of natura forest. From 1977 to 1997, the spatial extent of the forest had not changed very significantly Higher spatial resolution (15 metre visible bands) and spectral detail of the 2002 ASTER imagery gives a chance to get a detailed land cover map of the area, where good quality close canopy forest cover appears to cover only 560 hectares. The apparent increase in forest cove seen in the Landsat ETM+ 2003 results is probably due to its comparatively coarse resolution The classification produced from the fine-resolution Quickbird image (2003) supports the result

Some of the classes (i.e. closed canopy forest, open canopy forest, agro-forest) tend to overlap with one another in the spectral region, which suggests that there might be some chance of uncertainty in clustering pixels in the correct classes for closed forest and/or open canopy forest. Nevertheless, it can be argued from spectral signature analysis that forests are correctly separated from non-forest areas. The signature class for grassland in Landsat ETM+ and in ASTER (Figure 2) shows an offset in its distribution. This is probably due to the prevalence of dry grass in open areas. Figure 3a, 3b represents relative brightness (DN) values of some different images in relation to some selected land cover types.

6.4. Classification results: Land Cover Change in Madhupur Tract from 1962 to 2003

Temporal comparison of land cover was undertaken using data from different satellite sensors since no single source of data spanned such as long period. Due to the multi-date, multi-resolution nature of the data available, it is important to choose the methods for change analysis carefully (Coppin *et* al. 2004). There are a wide range of methods available for change analysis of satellite image data and it is important to be aware of the difficulties involved with multi-temporal comparison of vegetation. It is difficult to account for sensor related effects such has noise within the signal, view angle effects, spatial and radiomentric resolution. There can also be seasonal effects and difficulties of interpretation. Of all the techniques available, post-classification comparison is useful because each data set is classified separately therby removing the need for radiometric calibration between dates. The post-classification scheme aims first to separate forest from non-forest land cover types and so is insensitive to changes in cover types that are of no interest for this study (Colwell *et* al. 1980, Coppin *et* al. 2004). In the more recently acquired imagery it was possible to refine the classifications to include more detailed forestry classes. The technique is not perfect since errors can be introduced from a range of sources including selection of training data, image misregistration and poor quality image data.

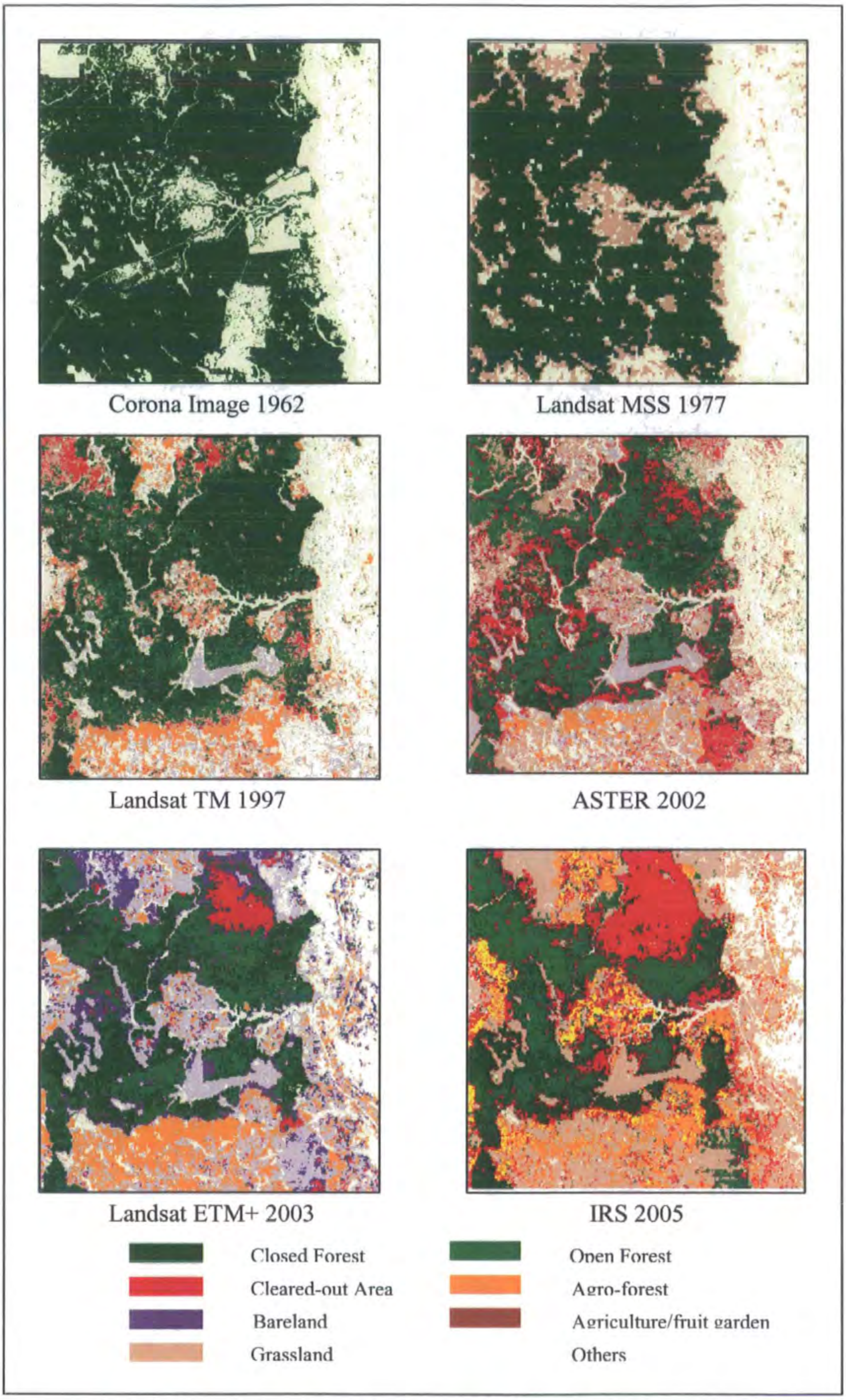


Figure 4: Distribution of forests in different satellite sensors. Maps in the box represents 80 X 80 kms area. Corona and Landsat MSS shows forest/non-forest classes.

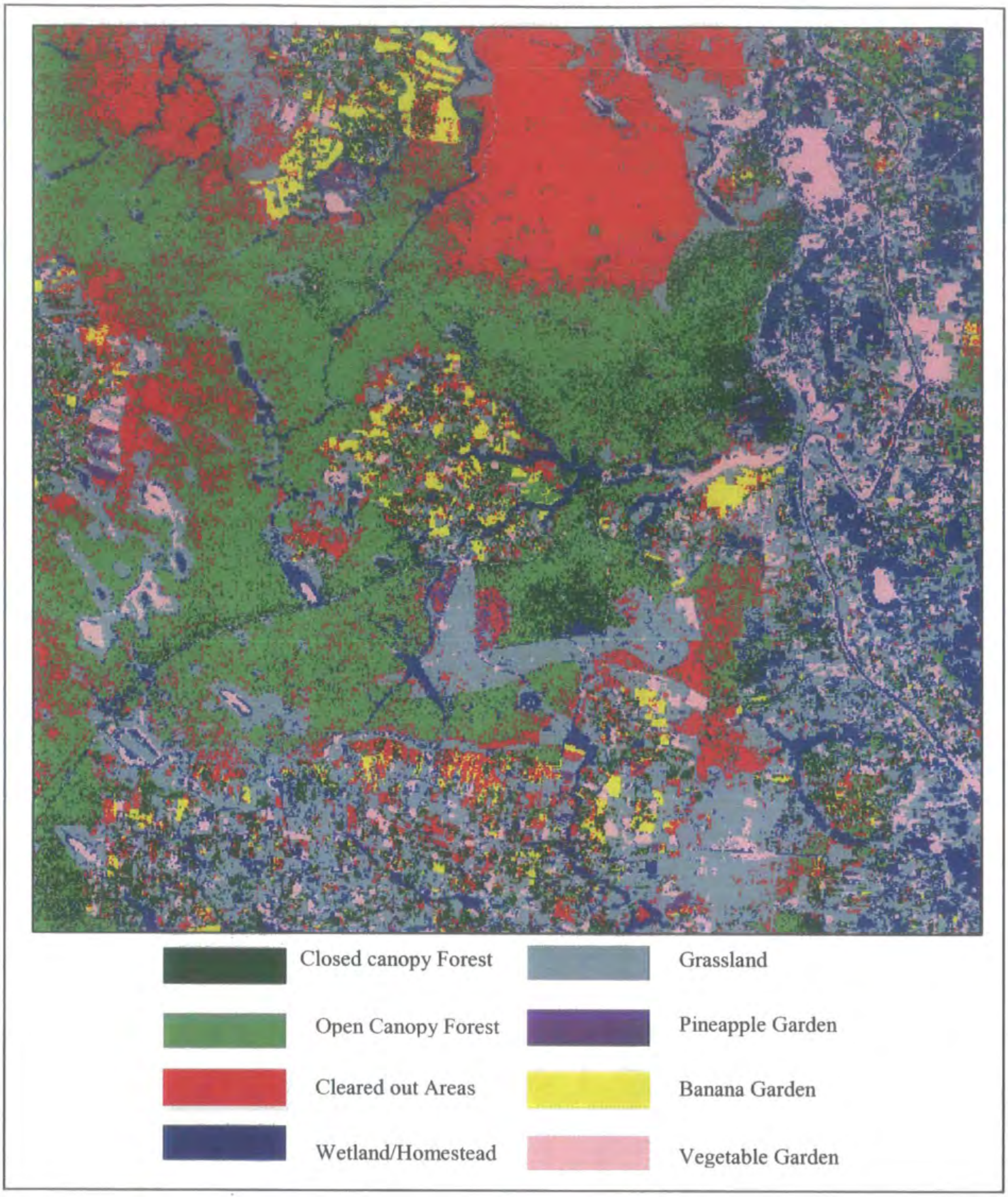


Figure 5: Land cover classes in Quickbird image (image captured in October 2003).

of ASTER. The Quickbird classification (figure 5, table 2) revealed 594 hectares as closed canopy forest and includes 1563 and 859 hectares as open canopy forest and cleared out/sa coppice area respectively.

6.5. Comparison of Landcover Classes in Madhupur Thana Map

In Bangladesh, statistics are generated on the basis of administrative units. Therefore, to compare the study results with published data, we need to produce maps and data over comparable areas. The following maps illustrate the land cover types of Madhupur thana. Current government data claims that 18,000 hectares of forest cover remains in the thana administrative unit (MoEF 1997). Analysis of the remote sensing data reveals the area with forest cover was approximately 2100 hectares (including closed canopy and open canopy forests) in 2003 (resulted in Landsat ETM+ image).

Figure 5 and 6 reveals a comparison of forest cover map of Madhupur thana produced using unsupervised classification algorithms.

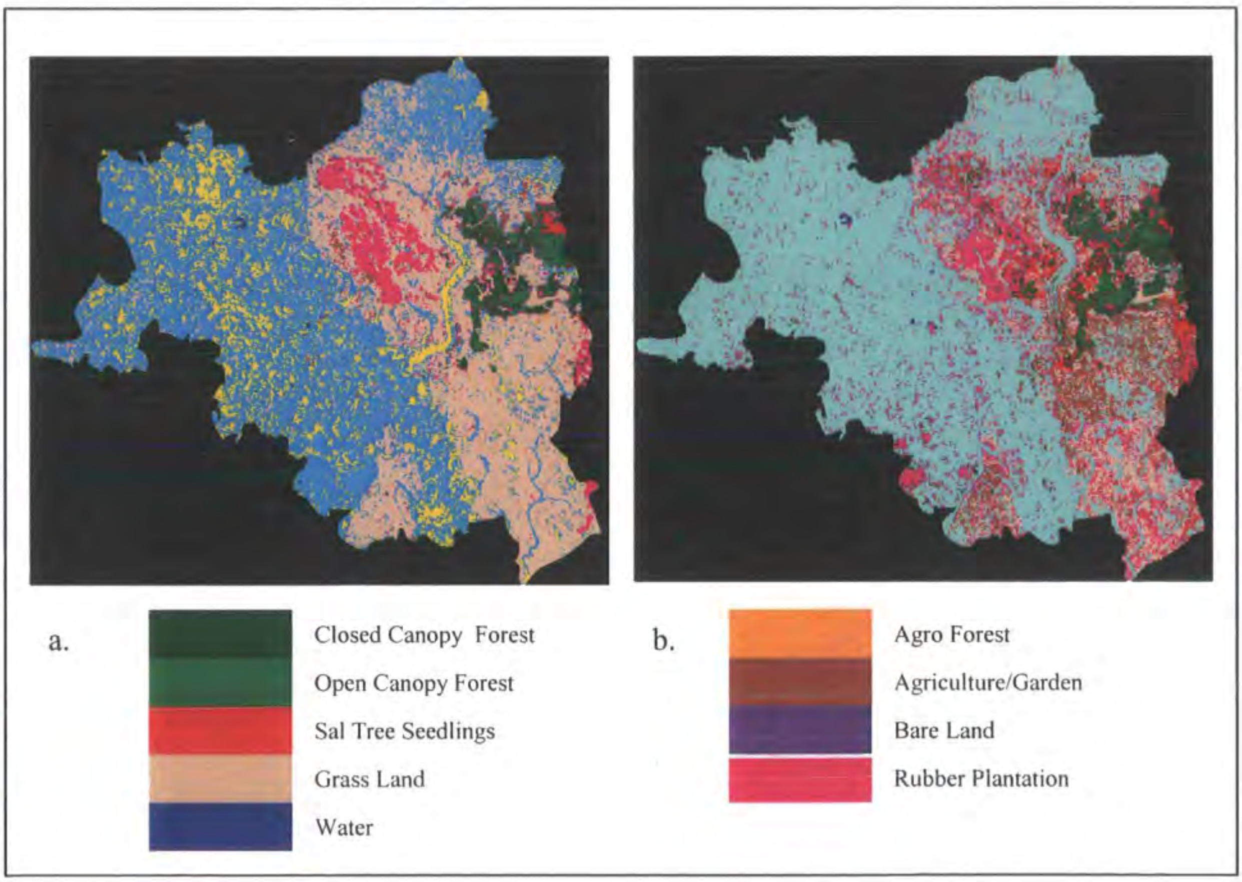


Figure 6: Land cover classification (unsupervised) in Landsat ETM+ 2003 (a) and Landsat TM 1997 image in Madhupur thana map (b).

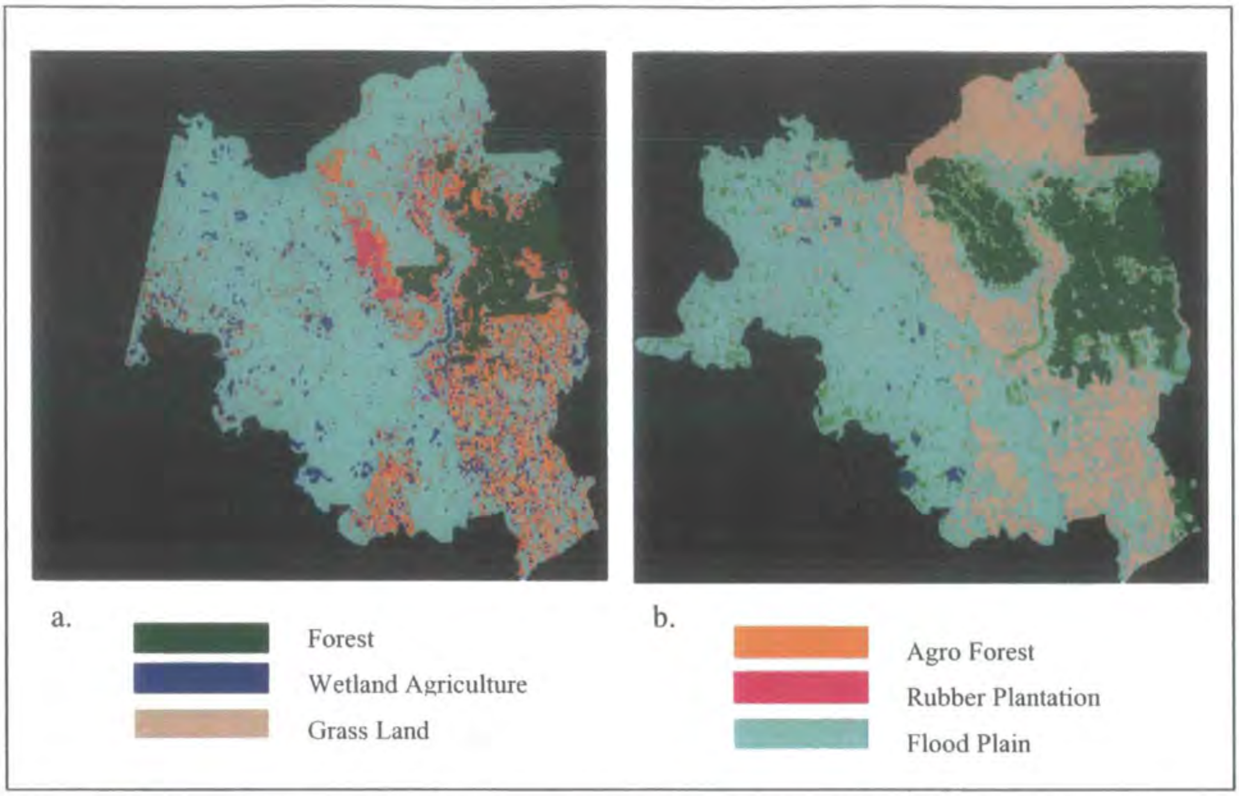


Figure 7: Land cover classification (unsupervised) in Landsat TM 1991 (a) and Landsat MSS 1977 image in Madhupur thana map (b).

6.6. Forest Cover Change in the Upper Part of Madhupur Tract

It is mentioned earlier that the deciduous sal forests in the central parts of the country are mainly located in the Madhupur Tract area. This special physiographic unit is spread over Dhaka, Tangail and Mymensingh districts of Bangladesh (Figure 7). Natural forests dominated by *Shorea robusta* species were distributed in all these districts in the past but deforestation has reduced their distribution mainly to the Tangail district. The maps presented in Figures 4, 5, 6 convey the pattern of deforestation for a relatively small part of the Tangail district. It is necessary to demonstrate and compare the land cover change at a broader scale so that overall change in the area can be put in context. So the area has been chosen equivalent to Corona satellite image scene as it covers major concentrations of sal forest distribution in the area and we have data available for this area from 1962 to present.

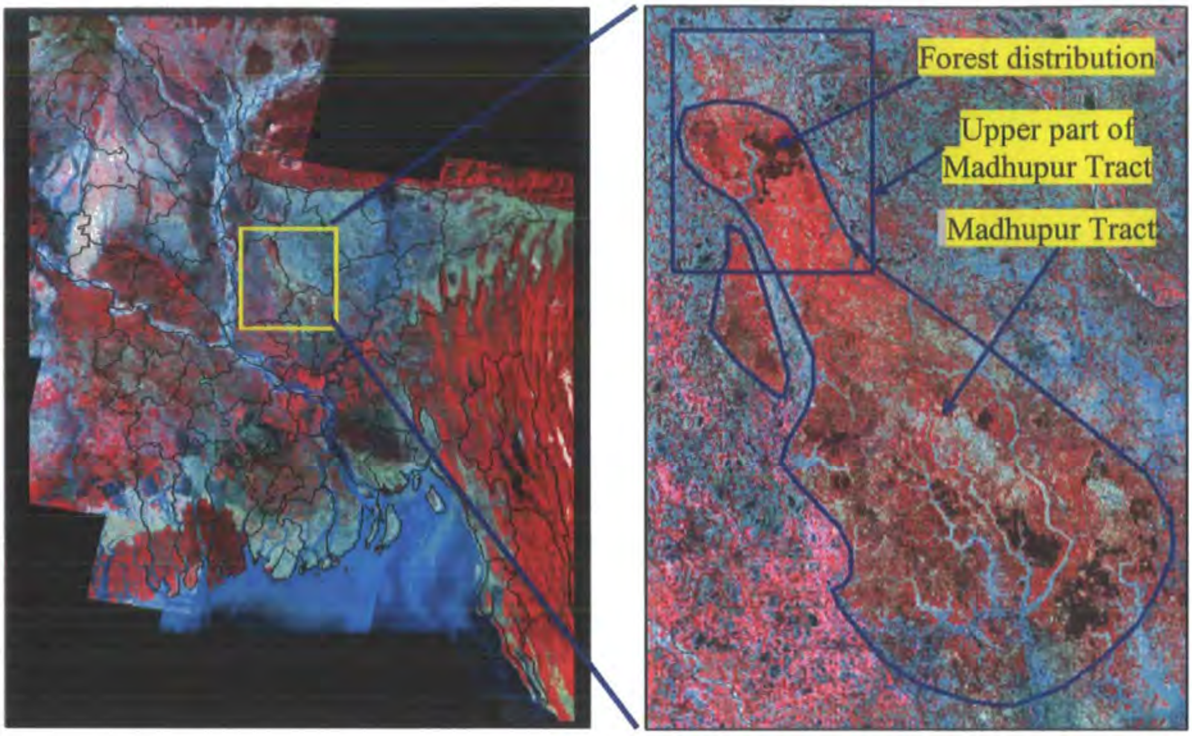


Figure 8: Location of Madhupur Tract in satellite image mosaic map of Bangladesh (left). Distribution of deciduous sal forest in the upper parts of that physiographic unit (right).

Forest and non-forest classes were identified from the time-series classifications generated using an unsupervised algorithm (Figure 10). An unsupervised classification algorithm was used because knowledge about the land cover classes in the historical imagery was limited, while this algorithm groups multiband spectral response patterns into clusters that are statistically separable. The results of unsupervised classification presented in Figure 10 suggests some mis-classification; the land cover map of 1997 (using Landsat TM data) showed some forest patches located at the bottom right corner that were missing in 1991 map. It also might be true that some *Shorea robusta* saplings sustained and grew as forest as the signs of forest in the same area can be found in 1962 and 1977 forest map. The initial classification results were checked through consultation with local key informants during the field visit in 2003. Most of the upper parts of the tract were under natural forest cover in 1962 and the area was calculated at about thirty thousand hectares, which was squeezed to only about two thousand hectares in 2005 (figure 9, 10).

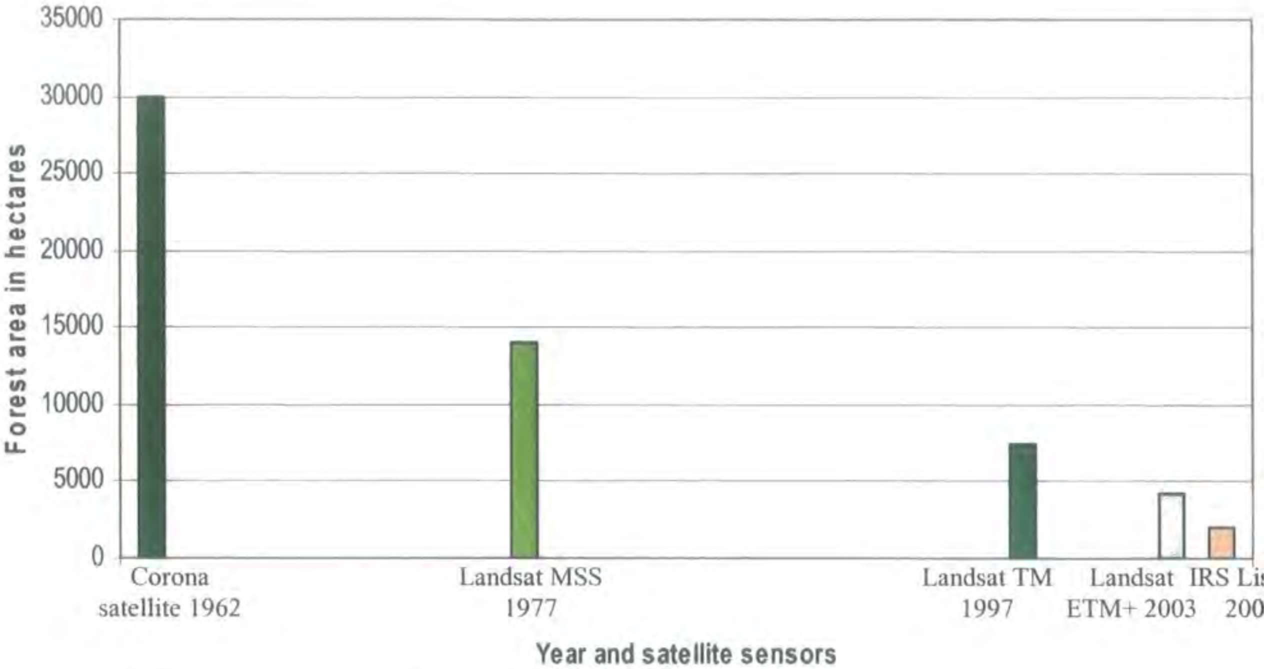
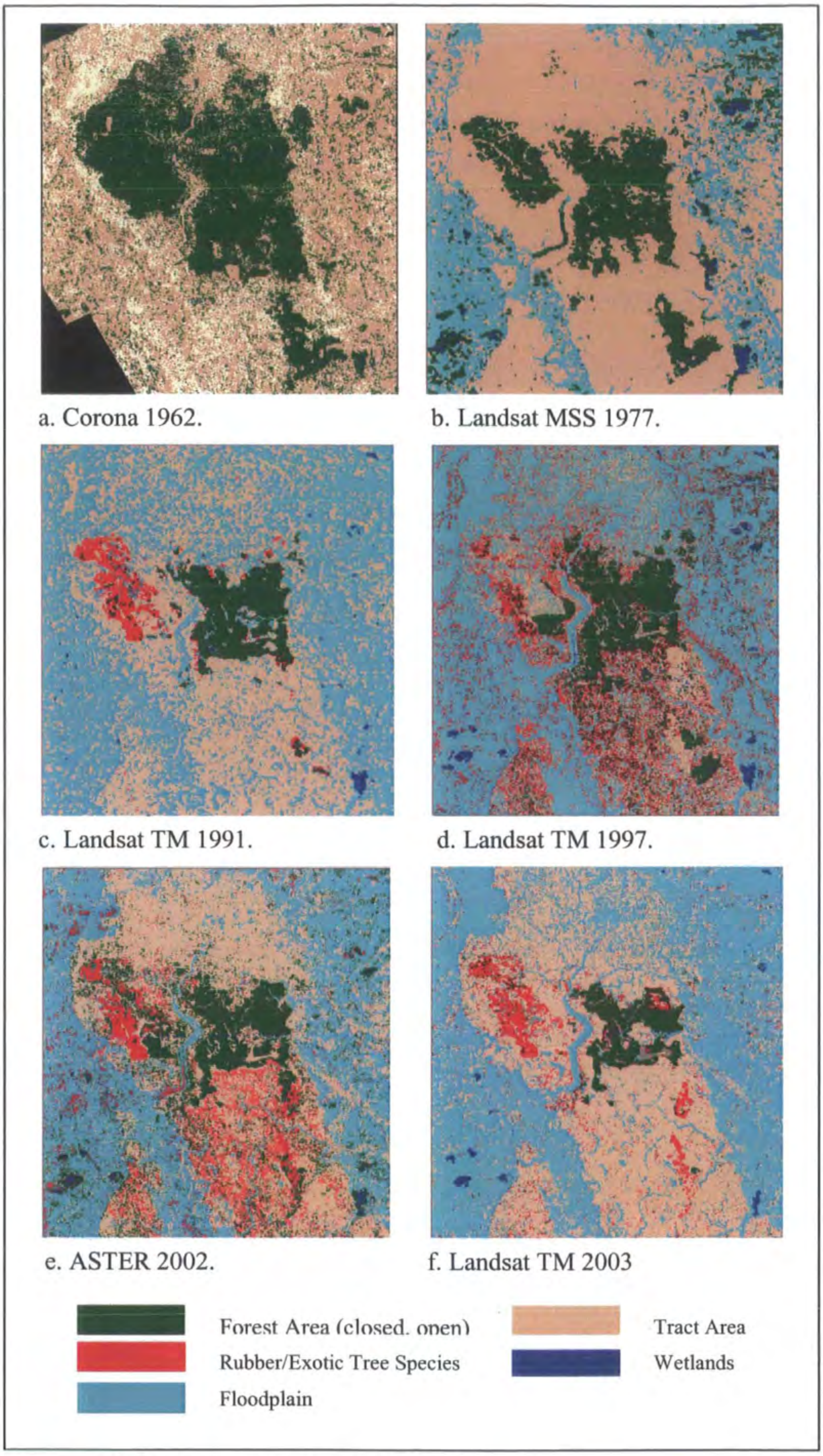


Figure 9: Forest cover in madhupur thana in different satellite sensors.



a. Corona 1962.

b. Landsat MSS 1977.

c. Landsat TM 1991.

d. Landsat TM 1997.

e. ASTER 2002.

f. Landsat TM 2003

Figure 10: Forest map distribution in Madhupur tract area.

This decline not only brought a change in forest area but also in forest quality. According to the key informants, the forests were covered with large old trees (dbh >50 cm) in the past but now is characterised with sparsely distributed smaller trees with dbh 16 to 20 cm and height 12 to 15 meters. At this moment, the remnants of the forest are located in Madhupur thana (under Tangail district). Forest and non-forest classes were mainly generated in the study area to compare the changes in spatial and temporal terms. But that did not give us any indication about the quality of current forest resources. The following sections, therefore, focused on the assessment of forest structural quality using established remote sensing methods.

6.7. Forest Structure Data Analysis

Forest plots are dominated by *Shorea robusta* trees in the Madhupur forest. Many other species are like Chatim (*Alstonia scholaris*), Arjun (*Terminalia arjuna*), Bahera (*Terminalia belirica*), Haritaki (*Terminalia chebula*), Amloki (*Phyllanthus embelica*), Palash (*Betua monosperma*) also found in the forest. But most of the trees were *Shorea robusta* species in the sample plots.

Table 3 shows a summary of the characteristics of the forest biophysical variables. The forest plots are broadly categorized into three major groups (i.e. closed canopy, open canopy and sa tree seedlings, described in chapter three). A large variation in dbh (minimum 5 cm, maximum 56 cm) is reported, where the average is 18.30 cm. The same kind of variation is also observed in the tree height data. It was observed during the field visits that sample plots having large trees (dbh >30 cm) are characterized by small number of trees and plots dominated by smaller trees have a larger number of trees. Table 3 also suggest that variability in tree density. Tree age is not a structural variable and it was not derived from an authentic source and so is marked in grey.

Table 3. Summary of measured forest parameters (n=49).

Forest variables	Mean	SD	Minimum	Maximum
DBH (cm)	18.30	10.28	5	56
Height (m)	12.35	4.18	3	23
Basal area (m^2ha^{-1})	10.96	5.37	0.45	29.54
Volume (m^3ha^{-1})	73.28	56.90	1	314.28
Tree Density (trees ha^{-1})	569	231.36	40	1160
Age (years)	14.7	9.8	1	50

Out of the 49 plots, 9 are treated as closed canopy and 36 represent open canopy conditions. Other 4 represent poor quality forest predominantly characterized by *Shorea robusta* saplings. It is sometimes difficult to differentiate this poor quality forests from degraded forests. The variation of forest structure has significantly reduced when sample plots are grouped into categories (table 4). For example, mean dbh for closed canopy sample plots are found 32.77 cm, where the standard deviation is 16.30. Mean dbh for open canopy sample plots is 16.20 cm, what is close to the dbh value (i.e. 18.30) for overall average. That indicates, open canopy conditions are dominated in the forest.

Table 4. Summary statistics of forest variables by forest quality.

Stand Quality	Forest Variables	No of obs.	Mean	Standard Deviation	Min.	Max.
Closed Canopy Forest	dbh	09	32.77	16.30	13	56
	Height		16.11	4.37	11	23
	Basal area		14.85	6.32	9.02	29.54
	Volume		122	96.96	37	314.28
Open Canopy Forest	dbh	36	16.20	6.19	4	36
	Height		12.04	3.56	3	19
	Basal area		10.55	4.73	0.6	25.32
	Volume		67.88	42.65	1	180
Shorea robusta Saplings	dbh	4	11.50	8.10	4	19
	Height		7.75	5.50	3	13
	Basal area		7.13	7.29	0.45	14.24
	Volume		29.75	39.18	1	84

Variation which may in part be attributed to the type or category of forest is also reflected in th correlation results (Table 4). For instance, Pearsons Product correlation values for the heigh variable in relation to dbh was found 0.83 (when considering all plots) was increased to 0.96 fo closed canopy sample plots (yellow marked in Table 5). Similarly, the correlation value fo volume in relation to height increased from 0.72 (all observations) to 0.86 (closed canop forests) though height is an indirect measurement for forest structural analysis using satellit sensor spectral data. Saplings sample plots show the highest level of correlation (for exampl r=0.99 for height versus dbh, r=0.98 for basal area versus height). It was observed fron fieldwork that poor quality stands are mainly dominated by homogenous pattern of *Shore robusta* tree saplings, this homogeneity might result in strong association between variable The scatter plot matrix (figure 11) also revealed that dbh, height, basal area and volume ar strongly and positively correlated, while tree density show negative association with most of th variables. Tree density shows a significant correlation with dbh and height for closed canopy forest (Table 5).

Table 5. Pearsons Product Correlation Coefficients for various forest biophysical parameters.

Stand Quality	Forest Variables	DBH	Height	Basal area	Volume	Tree density	Age
All observations	DBH	1.00	-	-	-	-	-
	Height	0.83	1.00	-	-	-	-
	Basal area	0.77	0.80	1.00	-	-	-
	Volume	0.78	0.72	0.85	1.00	-	-
	Tree density	-0.72	-0.55	-0.29	-0.45	1.00	-
	Age	0.74	0.60	0.54	0.67	-0.50	1.00
Closed Canopy Forest	DBH	1.00	-	-	-	-	-
	Height	0.96	1.00	-	-	-	-
	Basal area	0.81	0.84	1.00	-	-	-
	Volume	0.85	0.86	0.93	1.00	-	-
	Tree density	-0.94	-0.89	-0.60	-0.65	1.00	-
	Age	0.75	0.82	0.74	0.88	-0.61	1.00
Open Canopy Forest	DBH	1.00	-	-	-	-	-
	Height	0.81	1.00	-	-	-	-
	Basal area	0.78	0.73	1.00	-	-	-
	Volume	0.66	0.62	0.82	1.00	-	-
	Tree density	-0.53	-0.44	-0.10	-0.21	1.00	-
	Age	0.39	0.37	0.34	0.41	-0.16	1.00
Shorea robusta Saplings	DBH	1.00	-	-	-	-	-
	Height	0.99	1.00	-	-	-	-
	Basal area	0.98	0.98	1.00	-	-	-
	Volume	0.81	0.80	0.89	1.00	-	-
	Tree density	0.33	0.28	0.33	0.24	1.00	-
	Age	0.87	0.84	0.86	0.71	0.75	1.00

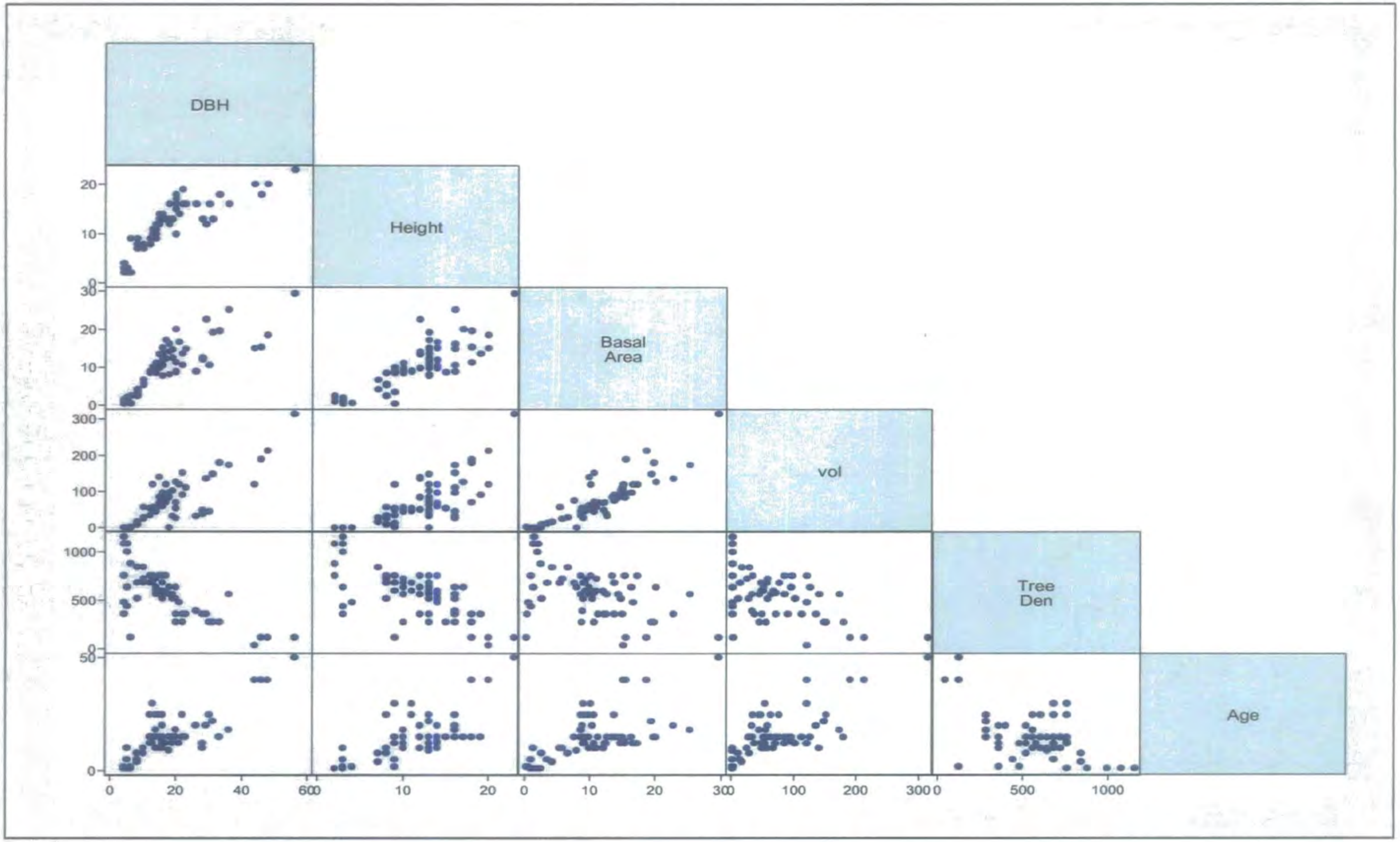


Figure 11. Scatter matrix of forest biophysical variables.

Interpretation of the scatter plot matrix shown in figure 11 suggests that the variables height, basal area and wood volume are positively correlated, but tree density shows a strong negative relationship with dbh. Examination of the scatter plot of the height variable against dbh indicates that trees in most of the sample plots fall under the height range 20 meters, dbh below 30 cm, basal area below 20 m^2/ha and volume under 150 m^3/ha. Sample plots with good quality trees (dbh >30 cm) are relatively fewer and distributed in the upper right corner of the plot and poor stands (dbh <25 cm) plot in the lower left corner. For tree density, number of trees reduces with an increase in dbh. This inverse relationship suggests that closed canopy sample plots do not permit saplings to grow as understorey.

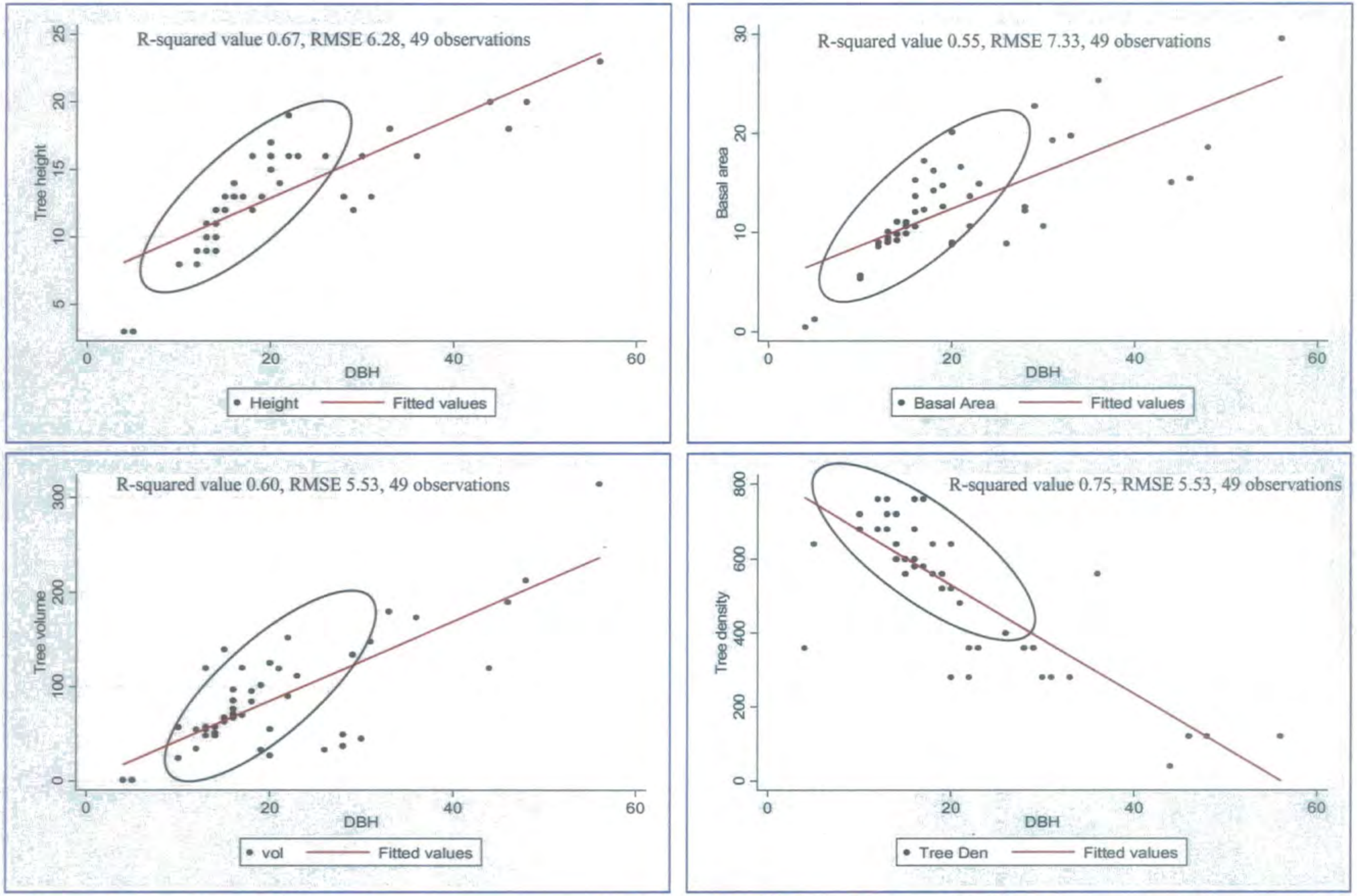


Figure 12: Distribution of forest biophysical variables in relation to dbh.

6.7.1. DBH Frequency Analysis

Diameter at breast height (dbh) measurements were taken for all trees (with dbh >5 cm) in a sample plot irrespective of its height or other properties. DBH is an important forest biophysical variable, which is used to determine the growth, volume, crop yield. It is mentioned in the earlier section that dbh is measured over bark using a girth tape. The frequency distribution of dbh (figure 13) shows that most of the plots (around fifty percent) remain within 20cm range and few stands represent high dbh values.

6.7.2. Stand Height Frequency

Tree height measurements were taken for all the trees in a sample plot and then the average is taken as a summary measure for that plot. A Suunto Clinometer was used for measuring tree height by trigonometry. Figure 8 shows that the distribution of tree heights are more uniform. About 30 percent of the trees represent height around 12-15m. This measurement also shows a similarity with dbh pattern and suggests that the mid-height (7-20 m) trees dominate the sample plots in Madhupur forest.

6.7.3. Frequency Analysis for Basal Area

Frequency analysis for basal area suggests no significant difference from dbh or tree height distribution. More than 50 percent of the sample plot represents basal area of about 10-15m^2 per hectare. Basal area more than 20 m^2/ha is limited to a very few sample plots.

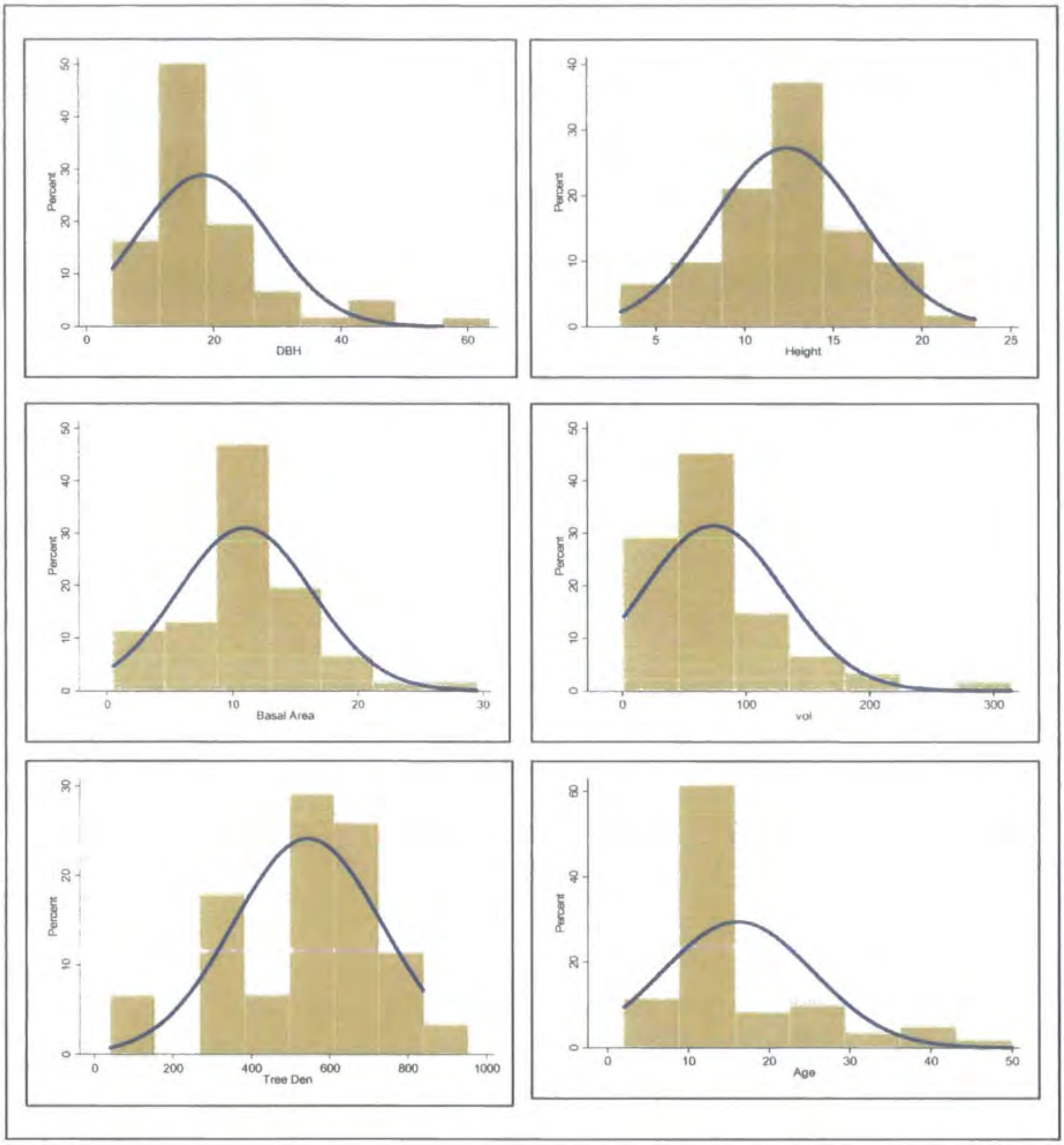


Figure 13: Forest structural variables in bar diagrams. Density plot curve (in blue line) gives an indication of variability.

6.7.4. Volume Distribution

The volume distribution is positively skewed (figure 13). More than 70 percent of the sample plots represent a wood volume $100m^3$ per hectare. Volumes were calculated according the volume table constructed for *Shorea robusta* tree species by Bangladesh Forest Department for different dbh class using field derived height and dbh measurements. The values were considered for over bark measurements. There were very few trees present other than *Shorea robusta* in the forest sample plots so the same volume table was used for all calculations. This may cause some small bias in wood volume estimation. The volume equations are based only on dbh and tree height, so it is important to note that in this context volume is not equivalent to biomass since a significant portion (e.g. leaves, tree branches) of the trees is not accounted for in the calculation. This is common for tropical forests and it means that the measure is presented for comparative. And it indicates that volume estimates are not precise. But the volume estimates derived from the volume table of Bangladesh Forest Research Institute (Das 1992) may give some generalized indication only about forest quality.

6.7.5. Tree Density Distribution

Trees per hectare (tree density) were determined by counting the total number of trees in each sample plot. Number of trees per unit area is much higher in poor and open canopy sample plots than closed canopy plots. It is mainly because it is difficult to sustain younger trees in an area when canopy closure occurs due to low level of sun light penetration. The ground in these plots was dominated by many varieties of shrub, cane (*Calamus dichotoma*) and grasses.

6.7.6 Tree Age Distribution

Tree age, although not a structural variable, was determined by consultation with local people and field forest officers. It can be noted that most of the plots show that about 60 percent of the trees fall in the range of 10-15 years (figure 13). Field observation also implied that most of the mature old aged tree have been removed from the forest. Only a few patches remain near the local forest offices.

6.8. Relationships of Forest Variables in respect to image spectral response pattern

Forest biophysical variables were modelled in relation to spectral response pattern of different satellite images using the STATA™ statistical analysis package. The techniques for extracting digital numbers are discussed in earlier chapter. Spectral information for several spatial windows were tested and the results show that the window sizes of 4X4 Landsat ETM+ pixel equivalent Quickbird (24X24=576) pixels gave the strongest relationship with forest structural variables. Table 6 shows a summary of the least squares linear regression results for Quickbird satellite image data summarized by the coefficient of determination (R^2 values). Quickbird band 3 and dbh, height, basal area and volume gave R^2 values of 0.28, 0.32, 0.43, 0.40 respectively when all sample plots were included in the model; for only closed canopy sample plots R^2 values increased to 0.67, 0.68, 0.49 and 0.78 respectively. Quickbird band 1 and 2 showed slightly weaker relation with forest variables than the near IR band 4 (760 to 900-nm) and band 3 "red" (630 to 690-nm).

The same analysis was carried out for Landsat ETM+ for closed canopy sample plots but the results give low R^2 values which indicates a weak relationship with forest variables see table 7 as expected.

Table 6. *R-squared* values between DNs of Quickbird image (using 24 X 24 pixels spatial window) and Forest Variables.

Stand Quality	Forest Variables	DBH	Height	Volume	Basal area	Tree density	Age
All observations	QB Band 1	0.22	0.28	0.34	0.37	0.06	0.29
	QB Band 2	0.37	0.49	0.50	0.56	0.10	0.43
	QB Band 3	0.28	0.32	0.40	0.43	0.06	0.28
	QB Band 4	0.29	0.43	0.36	0.42	0.08	0.36
Closed Canopy Forest (9 obs.)	QB Band 1	0.20	0.21	0.34	0.11	0.11	0.51
	QB Band 2	0.47	0.56	0.69	0.43	0.29	0.88
	QB Band 3	0.67	0.68	0.78	0.49	0.48	0.78
	QB Band 4	0.59	0.69	0.42	0.26	0.60	0.70
Open Canopy Forest (36 obs.)	QB Band 1	0.10	0.05	0.25	0.09	0.00	0.21
	QB Band 2	0.20	0.29	0.44	0.31	0.00	0.21
	QB Band 3	0.15	0.20	0.45	0.25	0.00	0.21
	QB Band 4	0.09	0.18	0.30	0.20	0.01	0.14
Shorea robusta Saplings (4 obs.)	QB Band 1	0.83	0.81	0.35	0.75	0.38	0.89
	QB Band 2	0.96	0.94	0.71	0.97	0.23	0.88
	QB Band 3	0.97	0.96	0.59	0.94	0.22	0.86
	QB Band 4	0.59	0.54	0.50	0.62	0.70	0.95

It is imperative to mention that forest variables such as dbh, height, volume are not measured directly by the satellite sensor. The results indicate the correlation between spectral information and forest variables.

Table 7. R^2 values summarising relationship between DNs of Landsat ETM imagery (using 4 X 4 pixel window) and forest variables (N.B. Volume is derived from tables)

Sensor		**Forest Variables**					
		DBH	**Height**	**Basal Area**	**Tree Density**	***Volume***	**Age**
Closed Canopy	**B2**	0.27	0.28	0.38	0.005	0.38	0.31
	B3	0.10	0.10	0.23	0.00	0.20	0.08
	B4	0.35	0.35	0.41	0.03	0.42	0.38
	B5	0.12	0.14	0.13	0.02	0.20	0.16
	B7	0.05	0.04	0.06	0.00	0.08	0.05

6.9. Impact of Spatial Window on modelling results

Relationships between spectral data and forest variables were found to be strong in closed canopy forest sample plots with Quickbird band 3 data when using a 24 X 24 pixel window. On the other hand a smaller sized spatial window (i.e 11 X 11 pixels) shows weaker relationships, see table 8. For instance, R^2 values of 0.18 and 0.12 for

Table 8: R^2 Values of Different Buffer DNs of Quick Bird Image (Band 2 and 3) and Forest Variables (dbh and Height).

Forest Variables	**Sample Class**	**11 x 11 = 121 pixels (27 x 27 m)**		**24 x 24 = 576 pixels (58 x 58 m)**	
		QB_B2	**QB_B3**	**QB_B2**	**QB_B3**
Dbh	Closed Canopy (9 obs.)	0.19	0.12	0.47	0.67
	Open Canopy (36 obs.)	0.05	0.01	0.20	0.15
	Sal Tree Seedlings (4 obs.)	0.97	0.99	0.96	0.97
Height	Closed Canopy (9 obs.)	0.18	0.12	0.56	0.68
	Open Canopy (36 obs.)	0.09	0.04	0.29	0.20
	Sal Tree Seedlings (4 obs.)	0.98	0.99	0.94	0.96

Quickbird band 2 and 3 respectively (using 11 X 11 pixel window) improved to 0.56 and 0.68 for the same variables when using 24 X 24 pixel window. Improved R^2 values for open canopy sample plots were also observed but the sample plots of sal tree seedlings did not show any major change. Peterson *et* al. (1986) and Olsson (1994) suggested this kind of stratification to improved model results. It is interesting to note that the plots containing sal tree seedlings showed the strongest relationship (R^2 up to 0.99). This result may be because canopy closure has occurred in both closed canopy plots and seedling plots, this is not the case for open canopy sample plots. Open canopy sample plots represent a mixed reflectance that might contribute to poor model relationships (Figure 14).

It is also observed that open canopy sample plots are characterized with different species from the other classes because most of the large sal (*Shorea robusta*) trees have been removed from these open sample plots and the remaining trees are mostly the leftovers with other species, e.g. koroi (*Albizzia procera*), jogini charka (*Gmelina arborea*), kaika (*Adina cordifolia*), sidah (*Lagerstroemia parviflora*), bazna (*Zathoxylum budrunga*), sonalu (*Cassica fistula*), ajuli (*Dillenia pentagyna*), gadila (*Careya arborea*) (figure 13). Franklin (1986) suggested the effects of species composition are important after canopy closure, when background reflectance no longer dominates the remotely sensed signal. Both of these factors (i.e. multiple species composition, ground vegetation) impacted on the regression results.

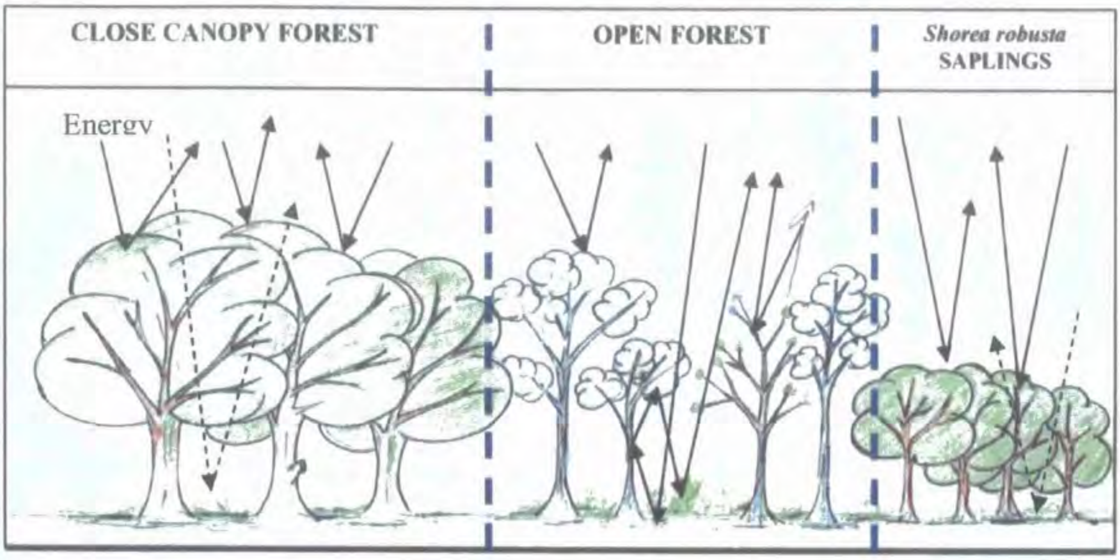


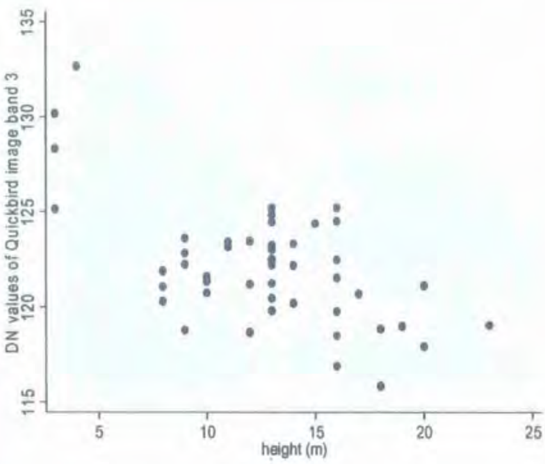
Figure 14: Schematic diagram of electromagnetic energy reflection pattern from forest patches in the study area.

6.10. Forest Variables versus Satellite Spectral Information

It was observed during the fieldwork that most of the healthy, old growth trees were removed from the forest except those areas placed in the close vicinity of the forest department because forest guards are more active in those areas. Therefore, sample plots were sub-setted before performing any analysis. Spectral information based on sample plots was then used to generate model results (Watt 2005) using single bands and different band combinations in relation to forest variables such as dbh and tree height. Fifteen model results were derived to take in all possible band combinations of Quickbird bands 1, 2, 3 and 4. Appendix 4 (table 1 and 2) summarize the regression and multiple regression results of dbh and height variable for different types of sample plots (i.e. closed, open canopy forests). In all of the sample clusters, the R^2 values, both for the dbh and height, increase as more bands are included. Sample plots having lower values of dbh or height are concentrated at the lower left corner and any increase in the variable values places the sample plots in the upper right corner of the scatter plot. It is observed that most of the visible wavelength bands, especially the Quickbird "red" band 3 demonstrate a strong relationship with forest variables. When bands are combined, model results improved, particularly when band 3 is included. The regression equation for Quickbird band 3 and (indirect variable) dbh and height variable was used as a crude indication of forest quality in the next section. In is hoped that the model map may help to yield useful information about the spatial pattern of forest condition or quality.

6.11. Forest Mapping Aided with Model Predictors

Forest mapping in terms of its health condition, stand structural properties or species pattern is an uncommon practice in the Bangladesh forest management regime. Forests are generally categorized as forest (having trees) or non-forests, where quality issues are always neglected. Predicting forest classes in terms of its biophysical variables (mainly based on dbh and tree height) is carried out in this study to help identify forest patches in terms of quality. Band 3 of Quickbird image was used for tree height and dbh predictions. Figure 14 and 15 shows the height and dbh plotted against Quickbird image band 3. Regression equations were developed according to the sample plot types (i.e. closed canopy, open canopy, poor/sal tree saplings plots),



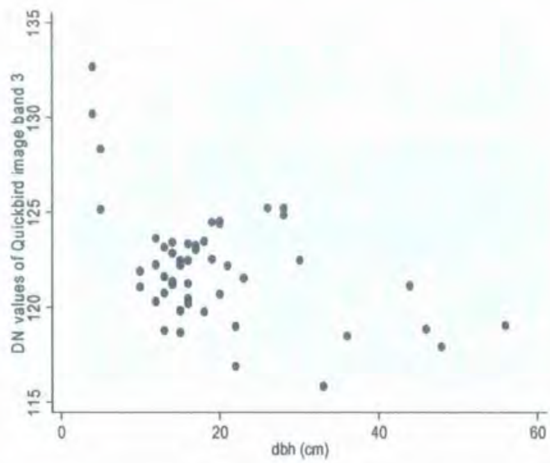


Figure 14: Distribution of height (m) values against DNs of Quickbird image band 3.

Figure 15: Distribution of dbh (cm) values against DNs of Quickbird image band 3.

(presented in Appendix 4). Linear regression models were then inverted to produce predictions of height and dbh using the Erdas Imagine Model Builder tool. The maps in figure 16 depict the predicted forest variables height and dbh predictions from the inverted empirical regression models (i.e. dbh = 710.028 – 5.57683 QB_b3 and Height = 199.9387 -1.513732 QB_b3). The equation is chosen from the first group of sample plots (i.e. closed canopy, n=9), as these plots are the true representation of *Shorea robusta* trees in the field. It could be argued that model 15 (Appendix 4) could be used as it showed highest R^2 (0.70, 0.80), but it was not used as regression values between band 3 alone and combination of bands 1, 2, 3 and 4 is not significantly different. It is also simpler to use single band for prediction. Simplification of the approach might have operational value for industrial level implementation.

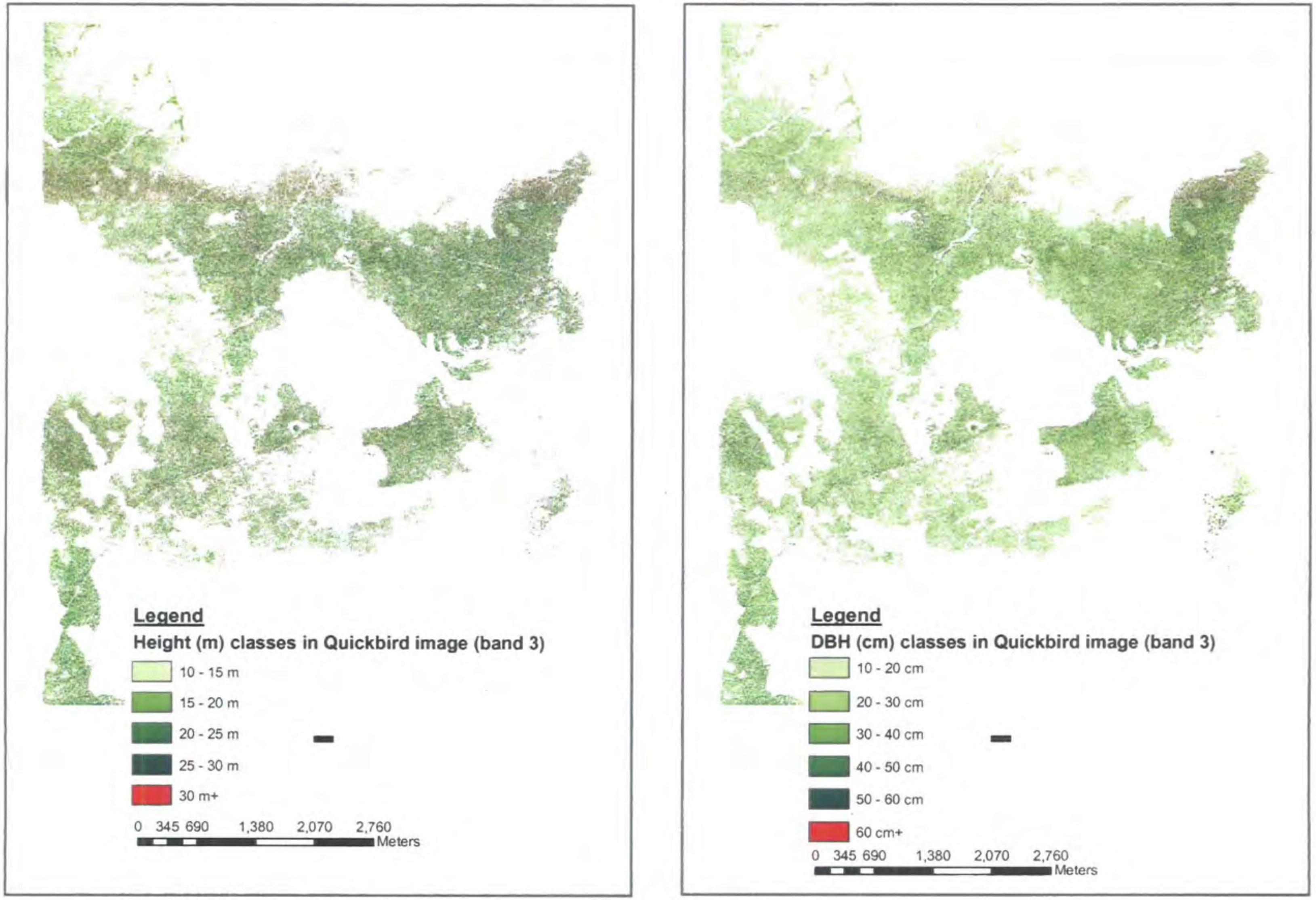
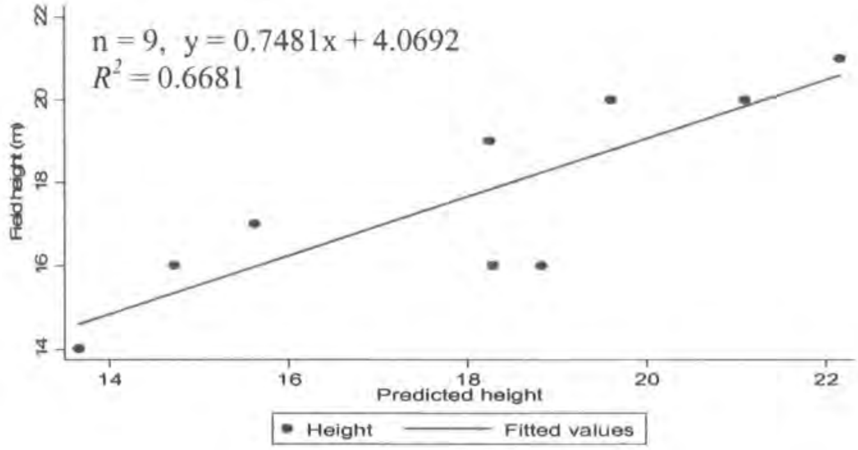


Figure 16. Height class map of Quickbird image (left), dbh map of the same image (right).

The height and dbh prediction maps (Figure 16) may correspond better to canopy cover as satellite sensors directly see that, however no field data was available to corroborate this. Nevertheless, the maps appear to correspond well with interpretation of forest quality as interpreted from the raw Quickbird image (Appendix 8).

6.12. Assessing the value of *Shorea robusta* height and dbh predictions

The predictions shown in figure 16 appear to make sense in terms of field experience and also correspond with image interpretation. They also correspond well with the Quickbird classification map presented in figure 4. The area of good quality forest (termed as closed canopy Forest here) in Madhupur is very limited indeed according to the spectral characteristics of Quickbird data. This implies that forest cover maps derived from low and medium resolution satellite data (and official government statistics) hide to a certain extent the scale of damage and degradation. However, there is still a need to assess their level of accuracy. The same size spatial window previously used for extracting spectral information (i.e. 24 X 24 pixels) was used to extract height information from the predicted map in the same fashion described in chapter 5. All the closed canopy sample plots (n=9) in addition to 14 sample plots from open canopy plots (altogether 23 sample plots) were chosen for height value extraction. The height value extracted from the predicted image were averaged tested with the field data (using only 9 closed canopy sample plots) which shows strong linear relationship as expected (figure 17, upper). The relationship was stronger (R^2=0.78) when 14 open canopy sample plots were added. This suggests that the regression equation is also useful for height prediction even for the open canopy sample plots. However, despite the encouraging statistical evidence, the map itself suggests that the model is affected by different objects (i.e understorey vegetation, shadow) in Quickbird image. Therefore, the empirical equation applied to Quickbird band 3 data might predict shadow or ground with moisture with higher tree heights because those objects absorbs more energy than tree canopy and appear dark.



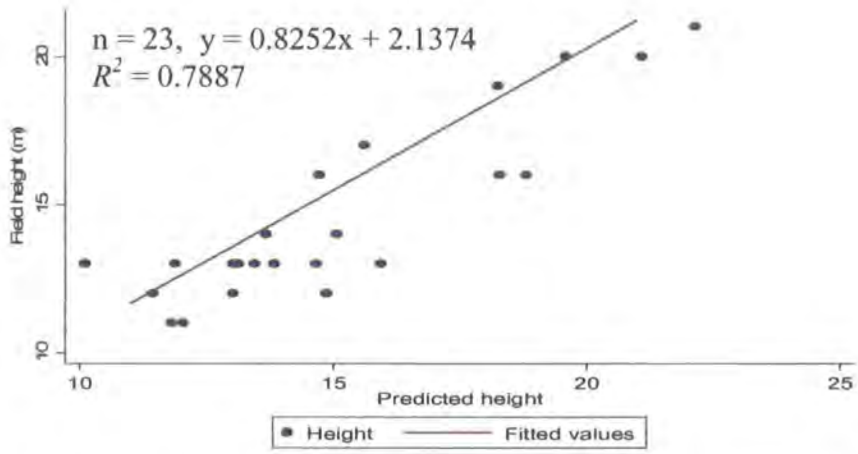


Figure 17: Comparing the results, predicted height versus field measured height. Scatter plot using 9 closed canopy sample plots (upper figure). Scatter plot for 23 sample plots (9 closed canopy, 14 open canopy plots) (lower figure).

The texture of prediction maps in figure 16 clearly suggest that continuum of pattern could not be achieved due to this problem. Tree height predictions > 30 m are probably wrong due to the effect of shadow. Figure 'a' in Appendix 5 shows this as red pixels but these are difficult to see. This problem can be dealt with using two approaches,

(i) using spectral mixture modelling or image thresholding to help identify shadow pixels and masking out those pixels. Then only apply regression model to tree canopy areas (Monteiro *et* al. 2003),

(ii) looking at the local neighbourhood to identify a sensible height value by applying filtering techniques.

Neighbourhood function filtering (at 3 X 3 and 5 X 5 pixel size) was applied to the predicted height map using the maximum and minimum functions. Forest height predictions were filtered for both the filter kernels. These sizes were selected as field experience suggests that the cross sectional length of tree crown is never bigger than 15 m X 15 m (about 5 X 5 pixel size). Figure 'a' in Appendix 5 shows the original height prediction map with apparent overestimations in red. These red pixels may be due to shadow effects in the Quickbird image. Height values filtered with the maximum function at a 5 X 5 pixel window (figure b in Appendix 4) highlights the problem of overestimations; values greater than 30 metres. The filtering window was reduced to 3 X 3 pixels for both maximum and minimum functions to see if this reduced the occurrence of overestimation. Appendix 5 (figure c), the 3 X 3 maximum height filter map, reduces the overestimation but it is still a problem. A minimum filter for height using a 3 X 3 pixel window (appendix 5, figure d) generates an underestimation of tree height as some tall trees in close vicinity to smaller will be missed. But this is useful because it acts to filter out unrealistic values. It may also be helpful to be able to show the minimum level of forest resource in the area. It is likely that the true situation would lie in between these two results and it appears that the original prediction map (figure 16 and Appendix 6, figure a) is quite accurate. This argument is also supported by histograms (Appendix 7) showing the distribution of height values in original model prediction. Figure 'a' in appendix 5 shows that highest tree height is not greater than 30 metres which was also supported by the field observations. The histograms also suggest that 5 X 5 window size is too large for filtering as tree height predictions rise to 60 metres, which is unrealistic.

Results show that the original height model predictions are the most useful result, even if shadow is a problem in some areas. Minimum filter does, however, give an indication of the minimum level of resource in the area.

Similar to the accuracy assessment of forest quality mapping, we need to assess the quality of (forest, non-forest) classification results that were used for spatial and temporal change detection presented in the earlier parts of this chapter. Because, various error sources, mentioned earlier, might undermine the results. So, assessing the accuracy of the classification work (see the following sections) may give us indication how better the results are for using it in forest management.

6.13. Accuracy Assessment Results

The image classification results done earlier this chapter need an accuracy assessment since errors may be introduced from different sources as mentioned earlier. The accuracy assessment results are presented in table 10 and 11 based on the methods presented in chapter 2, where it also focused on some pertinent literature on the issue.

The overall maximum likelihood image classification accuracy for Quickbird is 78.04 percent and the overall kappa statistic is 0.72. On the other hand, these results for Landsat ETM+ are 84.26 percent and 0.81 respectively. The producer's accuracy ranges from 60 percent ("Fruit Gardens") to 100 percent ("Close Canopy Forest") and the user's accuracy varies from 46.67 percent ("Vegetable Gardens") to 100 percent ("Fruit Gardens") for Quickbird classification. In the case of Landsat ETM+ classification results, producer's accuracy and user's accuracy vary from 94.34 percent ("Close Canopy Forest") to 50 percent ("Cleared out Areas") and 87.72 percent (Close Canopy Forest) to 71.43 percent (Grass Land). This research is focused on mapping forest occurrence and its change and so the most interesting categories are "Closed Canopy Forest", "Open Canopy Forest" and "Cleared out Area". The estimates for "Closed Canopy Forest" class show a high level of accuracy for both Quickbird and Landsat ETM+ in terms of both producer's and user's accuracy. This is supported with corresponding kappa values of 0.82 for Quickbird and 0.85 for Landsat ETM+ classifications. Some confusion arose between "Open Canopy Forest" and "Cleared out Areas" since these two classes sometimes show similar characteristics though they appear to be spectrally separable in both Landsat ETM+ and Quickbird imagery. Although the other classes give an impression about the land use dynamics in the study site, these are not the primary concern of this study. The overall accuracy assessment results for Quickbird and Landsat ETM+ classification (i.e. 78.04 % for Quickbird and 84.26% for Landsat ETM+) suggest that they are almost similar. This may be because only broad categories are selected for classification. For instance, closed canopy, open canopy, cleared out area, water, agricultural lands, agro forest predominantly with acacia species are all land classes which for Landsat ETM+ imagery appear spectrally separable. For Quickbird classification, the land cover classes could be more detailed (to include fruit and vegetable gardens) and so the classification is slightly different from Landsat ETM+. From the samples studied, all the classes were spectrally separable in the Quickbird imagery.

Table 10: Accuracy assessment results of Quickbird (October, 2003) satellite image classification (employing maximum likelihood method).

		Training Set Data (Known cover types)							
		CCF	OCF	CA	GL	W	F	V	Total
Classification	CCF	15	3	0	0	0	0	0	18
	OCF	0	48	10	1	1	0	0	60
	CA	0	6	33	2	1	0	0	42
	GL	0	5	4	61	6	2	2	80
	W	0	2	1	3	29	0	0	35
	F	0	0	0	0	0	6	0	06
	V	0	1	0	2	2	2	7	14
	Total	15	65	48	69	39	10	9	255

Producer's Accuracy

CCF = 15/15 = 100%
OCF = 48/65 = 73.85%
CA = 33/48 = 68.75%
GL = 61/69 = 88.41%
W = 29/39 = 74.36%
F = 6/10 = 60.00%
V = 7/9 = 77.78%

User's Accuracy

CCF = 15/18 = 83.33%
OCF = 48/60 = 80.00%
CA = 33/42 = 78.57%
GL = 61/80 = 76.25%
W = 29/35 = 82.86%
F = 6/6 = 100%
V = 7/14 = 46.67%

Overall accuracy = (15 + 48 + 33 + 61 + 29 + 6 + 7)/255 = 78.04%

Kappa statistic, k^

Overall kappa statistic is 0.72, where

CCF - 0.82
OCF - 0.73
DF - 0.73
GL - 0.67
W - 0.79
F - 1.0
V - 0.44

CCF- Closed Canopy Forest, OCF- Open Canopy Forest, DF- Degraded Forest, GL- Grass Land, W- Water/Low Lands, F- Fruit Gardens, V- Vegetable Gardens.

Table 11: Accuracy assessment results of Landsat ETM+ (January, 2003) satellite image classification (employing maximum likelihood method).

		Training Set Data (Known cover types)								
		CCF	DF	CA	BA	GL	W	AG	AF	Total
Classification	CCF	50	3	3	0	0	0	0	1	57
	OCF	3	42	3	0	0	0	1	0	49
	CA	0	0	7	2	0	0	0	0	09
	BA	0	1	1	20	2	0	0	0	24
	GL	0	0	0	0	15	4	2	0	21
	W	0	0	0	0	4	48	3	0	55
	AG	0	1	0	0	1	3	55	6	66
	AF	0	0	0	0	0	0	4	20	24
	Total	53	47	14	22	22	55	65	27	305

Producer's Accuracy

CCF = 50/53 = 94.34%
OCF = 42/47 = 89.36%
CA = 7/14 = 50.00%
BA = 20/22 = 90.91%
GL = 15/22 = 68.18%
W = 48/55 = 87.27%
AG = 55/65 = 84.62%
AF = 20/27 = 74.07%

User's Accuracy

CCF = 55/57 = 87.72%
OCF = 42/49 = 85.71%
CA = 7/9 = 77.78%
BA = 20/24 = 83.33
GL = 15/21 = 71.43%
W = 48/55 = 87.27%
AG = 55/66 = 83.33%
AF = 20/24 = 83.13%

Overall accuracy = (50 + 42 + 7 + 20 + 15 + 48 + 55 + 20)/305 = 84.26%

Kappa statistic, k^

Overall kappa statistic is 0.81, where,

CCF - 0.85	GL - 0.69
OCF - 0.83	W - 0.84
CA - 0.76	AG - 0.78
BA - 0.82	AF - 0.81

CCF- Closed Canopy Forest, OCF- Open Canopy Forest, CA- Cleared out Area, BA- Bare Land, GL- Grass Land, W-Water/Low Land, AG- Agricultural Land, AF- Agro-forest.

6.14. Discussion

The classification results derived from remotely sensed image data shows a significant change/decrease in forest land cover in the study area. It was revealed that over the last forty years a naturally grown forest has almost been depleted. Figure 18 gives a summary of land cover change in the study area. Total area presented in figure 18 is equivalent to Quickbird image scene size (i.e. 64 square kilometres). This Quickbird image spatial extent is used for temporal forest area comparison because all the images were available for this spatial area and that is necessary for consistent temporal analysis. It is revealed that closed canopy forest has been reduced from an apparent area of 3800 hectares in the 1962 Corona KH-4 image to about 600 hectares in 2002/2003 based on assessment of ASTER and Quickbird data. It also showed that forests appeared largely intact in the early 1960s in the study area and no major deforestation occurred until after 1977 as shown by the Landsat MSS imagery. After that time rapid deforestation is seen in the time-series of images and continues up to the present day. Consultation with the local key informants during field work (see chapter 2) provides a picture consistent with the image analysis. The uneven nature of the intensity in the process of deforestation indicates that the scale of deforestation appeared to be happened at different spatial and temporal scales. In the study area the process of deforestation was rapid and it has fragmented the forests into smaller parts/patches mostly in recent times. In the earlier stages the forests were intact and the process of change appears to be slow. The pattern of recent rapid change suggests that the higher spatial resolution imagery is likely to be of considerable value as areas of high quality forest land are squeezed out and it becomes more important to separate intact and degraded forest types. For this type of work it will be important to have images with appropriate spatial scale and also high temporal resolution. Aplin (2006) supports these arguments by pointing out that "*different scales of observation are required to match the spatial scales of the process under observation; at the same time temporal sampling rate of the observing systems must be reconciled with the dynamics of the process observed*". He also suggests that "*bringing together these issues requires insight, innovation and inevitably, compromise*". This study, therefore, used higher spatial and temporal resolution images to help characterise recent change so that nature and pattern of deforestation and degradation can be identified accurately.

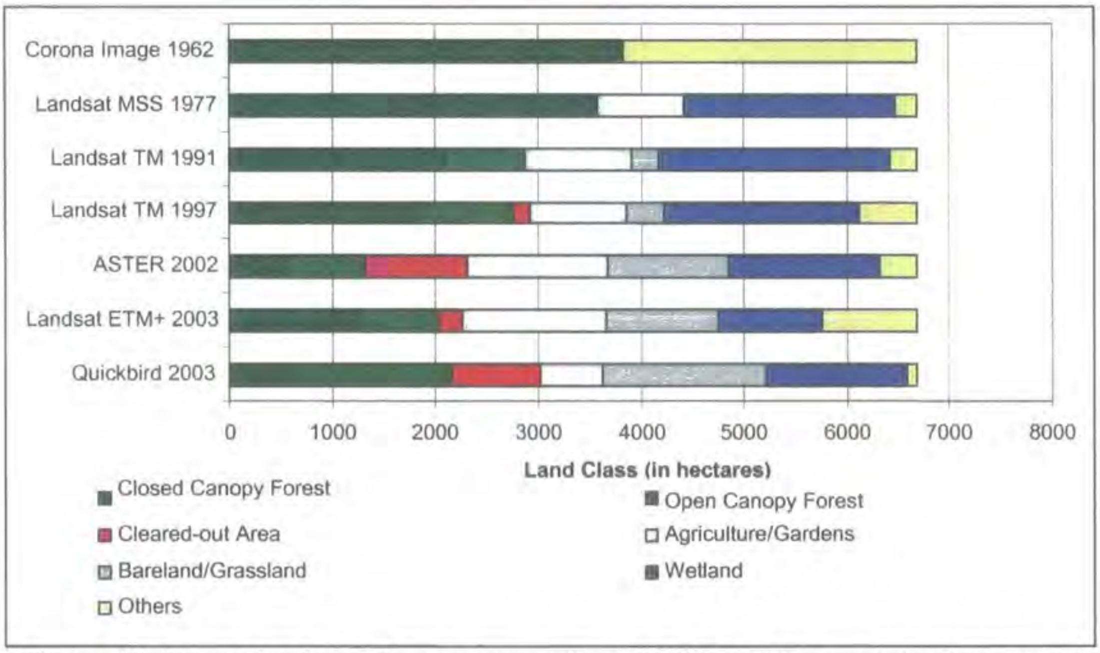


Figure 18: Forest land use change comparison (Quickbird imageequivalent spatial extent).

Due to this difference in spatial and temporal resolution of satellite images, the post-classification comparison method (Serra *et* al. 2003, Singh 1989) was selected for change detection rather than considering simultaneous analysis of multi-temporal data like image differencing, vegetation index differencing, principal component analysis, change vector analysis (Fung and LeDrew 1987, Eastman and Fulk 1993, Lambin and

Strahler 1994, Salvador *et* al. 2001). In the post-classification method, separately classified multi-temporal images are compared to assess the change. The main advantage of this method is, it minimizes the impacts of atmospheric, sensor and environmental differences between multi-temporal images and provides a complete matrix of change information (Lu 2004). That means the need for accurate radiometric corrections, which are difficult to achieve, are not necessary for post-classification change analysis since independently classified rather than original (spectral) images are being compared (Aplin 2006, Serra *et* al. 2003, Nichol and Wong 2005). In detecting Land Cover Land Use (LCLU) change, researchers like Brondizio *et* al. (1994), Dimyati *et* al. (1996), Miller *et* al. (1998), Foody (2001) also successfully used post-classification comparison methods. It should be noted as well that errors in classification and mis-registration may impact the results of post-classification technique (Singh 1989, Lambin and Strahler 1994). In this study, classifications are carried out on broad categories such as forest, non-forest in earlier images compared to detail-level classifications in the later images. Sufficient training samples were taken for supervised classifications to avoid uncertainties and to improve the classification results. Classification accuracies (overall accuracy) of supervised classification accounted for 84.26% for Landsat ETM+ 2003 and 78.04% for Quickbird 2003 image, suggest that classification results are fairly good. Accuracy assessment could not be undertaken on the remaining images like Corona (1962), Landsat MSS (1977), Landsat TM (1991 and 1997), ASTER (2002), IRS (2005); statistical separability using unsupervised classification algorithm technique was applied to these data. Accuracy assessment was carried out only on Landsat ETM+ (2003) and Quickbird (2003) image because fieldwork was carried out in the same year (i.e. in 2003). Therefore, it is obvious the results are not completely precise/error free but it certainly provides confidence that the forest cover maps are reasonably accurate and not the result of chance. The results of this study are significant since the official government statistics results do not shows any significant forest cover change over the same period (see Gani 1990, MoEF 1997, Farooque 1997). This study is also useful as it focused on the differences between observations of deforestation at the local scale and apparently misleading official data. The official estimates are transmitted by the government to international agencies such as the FAO, which compiles the global estimates of forest cover every 10 years (Zhu and Waller 2003). For instance, the national estimate of forest cover of Bangladesh government source 10.3% (www.bforest.gov.bd, accessed on 15 August 2006) is congruent with sate of world forest (FAO 2005b) estimate for Bangladesh for the year 2000 (i.e. their estimate is 10.2%). But results from this study suggest that about 85% of forests (in the study area) have been cleared out during the last 40 years. Foody *et* al. (2001) also indicated that scientists are often uncertain about the forest dynamics in the tropics. So, despite some limitations in accuracy it can be said that this study results appear to be more reliable than the national (like Bangladesh government) or international (like FAO) estimates and these data may help to understand some of the complexities of deforestation and tropical forest resource estimates.

The CORONA KH-4 satellite imagery used in this study is different from other images since it was recorded by a panoramic camera on photographic film. The panchromatic film was supplied as a copy in negative format from the USGS and scanned on a Vexcel VX4000 photogrammetric scanner to digitise the imagery at the optimal 7.5 μm (about 3400 dpi) optical resolution. This is the highest optical resolution that this scanner can achieve. The KH-4 camera had stereo capability, in this study only the forward looking image was used. According to NRO (1970a), the performance nadir prediction of the second generation Petzval lens used in KH-4 is 130 line pairs per millimetre (lp/mm). The film resolution shows that the film granules resolve at 3.8 and 3.2 μm respectively and so the quality of the image data is surprisingly high for the period (Galiatsatos et al, submitted; Peebles, 1997).

The task of distinguishing forestry from non-forest areas in Corona KH-4 image used a combination of tonal difference and traditional photo interpretation. It was important to ascertain that all the darker tone areas are indeed forests. Darker tones might also represent recent plantation, bush, wetland or agricultural crops. It was often difficult to demarcate land cover classes especially on the edge/boundary between classes as the tone of the Corona image might show the similar pattern throughout the continuum of vegetation. Therefore, it is likely that KH-4 data will overestimate forest areas in Corona satellite image by incorporating non-forest areas into forest category. Nevertheless, careful photo interpretation, analysis of spatial pattern, associations, and the use of key-informants all helped to validate the results (same method was also considered by Shepard, 2004); it is mentioned in chapter 2 that among the most helpful key informants were elderly school teachers and a father of a local church. These were educated people with a good local knowledge and an understanding of aerial photography and forestry. They helped by identifying forest and non-forest areas on georeferenced prints from the CORONA KH-4 images during the field visit. In addition, historical topographic maps, though not very accurate, were also consulted to help assess the results derived from Corona satellite imagery. A most encouraging feature of KH-4 CORONA imagery is the unusually high spatial resolution (approximately 8 m) that is detailed enough to interpret significant topographic features. Even though CORONA may yield a slight overestimate forest cover for 1962, and it contains no information on separating intact from degraded forest, it gives a very clear picture of the spatial pattern and extent of forest cover for the period. It is important to mention that the only alternative source of data lies with official government statistics and classified aerial photographs. Use of the aerial photographs is prohibited for research purposes. Without independent sources of imagery such as CORONA, a time series analysis would be impossible.

The availability of civilian satellite sensors since the introduction of the Landsat programme in 1972 brings new opportunities for forest cover mapping. Landsat MSS, TM and ETM+ use digital multispectral sensors that allow land cover to be separated from reflectance data. There is a large literature that demonstrates the capability of multispectral image classifications for a range of different land cover mapping applications including forestry. No surprisingly the more recent TM/ETM+ instruments are able to discriminate among more cover types than the original Landsat MSS 4 channel sensor. In theory, it should be possible to measure changes in surface reflectance that correlate with forest cover. However, it is recognised that there are considerable difficulties in providing accurate radiometric intercalibrations among these sensors. Radiometric calibration is possible but that any quantitative change detection using the radiometry would also have to account for subtle atmospheric and illuminations effects as well as seasonality and decay in sensor performance. Such problems can be avoided to a large extent by adopting a post-classification change analysis approach as outlined in chapter 5. IRS LISS-III image gave opportunity by providing higher spatial resolution (24 meters) data than Landsat sensors with a wide areal coverage. This may be considered as excellent opportunity, particularly to interpret land cover / land use types based on image interpretation. This also indicates that training areas can be identified more easily; better radiometry may mean that tree shadow effects are lessened. However, the increased spatial resolution also means that classification becomes more complex when the full ranges of cover types have to be accounted for (Aplin 2006). Townshend and Justice (1988), Pax-Lennez and Woodcock (1997) recommended the use of coarse resolution satellite imagery in cases where feature of interest (e.g. forest patch) are larger than the spatial resolution of the imagery because finer pixels may misclassify some features.

However, it was a challenge to use remote sensing methods in this particular context since Bangladesh forests are heterogenic in nature and human impacts are widespread. Therefore, generating training areas for right classes was a difficult task. The forest floors are dominated by understorey vegetation of various kinds. Some forest floors have grass, some are characterised by creepers, and different spice plants (like ginger, turmeric) planted by the forest department/local people through forest improvement projects (like agro-forestry schemes). So some spectral impurity in pixels representing forest classes may occur due to the presence of understorey vegetation.

The young green saplings of *Shorea robusta* gave very high reflectance values (high digital numbers) whereas the large mature trees give relatively low reflectance values (low DN values). This pattern can in part be explained by mutual shadowing and a decrease in the reflectance component derived from near ground succulent vegetation. Mutual shadowing increases as a stand grows older; the net effect is a decrease in reflectance since a larger and larger part of a pixel area will be in shadow. The effect of shadowing compensates the effect of increasing leaf biomass, which would otherwise increase reflectance, particularly at NIR wavelengths (Gjertsen, 1991).

Puhr *et al.* (2000) argued that it is difficult to predict forest condition from coarse resolution Landsat TM data even for the well managed conifer forest plantations in northern Europe. Others like Williams (1986), Nilson and Peterson (1994) also mention the difficulties of using satellite imagery to predict forest parameters/classes from tree stands at a per pixel level. Therefore, it should be more difficult to use coarse resolution data (like Landsat sensors) for classifying poorly managed, dissected forest stands especially in Bangladesh context. For instance, the area classified as closed canopy forest seems too high (about 1200 hectares) in Landsat ETM+ from 2003. A comparable data set acquired by the ASTER sensor in 2002 yielded a figure of about 560 hectares for closed canopy forest, see figure 18. In this case we may rely on ASTER results as it is supported by the results from Quickbird in 2003 (about 594 hectares estimated) which have been validated with ground based observations. High resolution Quickbird image data appeared effective to classify different forest land cover classes. Field data (from 49 sample plots) were used to check the classification results (of Quickbird, and Landsat ETM+ data) as both information/data (i.e. field and image) were captured at almost the same time. Figure 19 compares the satellite derived figures with government statistics. The tall green bar in figure 19 shows the current government estimate of forests for Madhupur thana, which indicates that the government statistics appear to be exaggerated compared to the results from this study. This government data may appear exaggerated for two reasons. First, the forest department wants to show that their activities and forest management/protection roles are operating faultlessly by representing a good amount of forest cover in the statistical reports; it also helps them to hiding the facts (i.e. the deforestation) from further debate/discussion and scrutiny. Secondly, forest lands in Bangladesh designates/signifies an administrative or legal category, not necessarily areas with forest cover. Therefore, no change in forest cover appeared in statistical reports as administrative boundaries are not generally a subject of change. Thus it can be said the approach and motives that Bangladesh forest department maintains, contributes to a very unclear impression about actual forest cover. Hence, remote sensing application could be the only alternative for unbiased reliable and repeatable mapping.

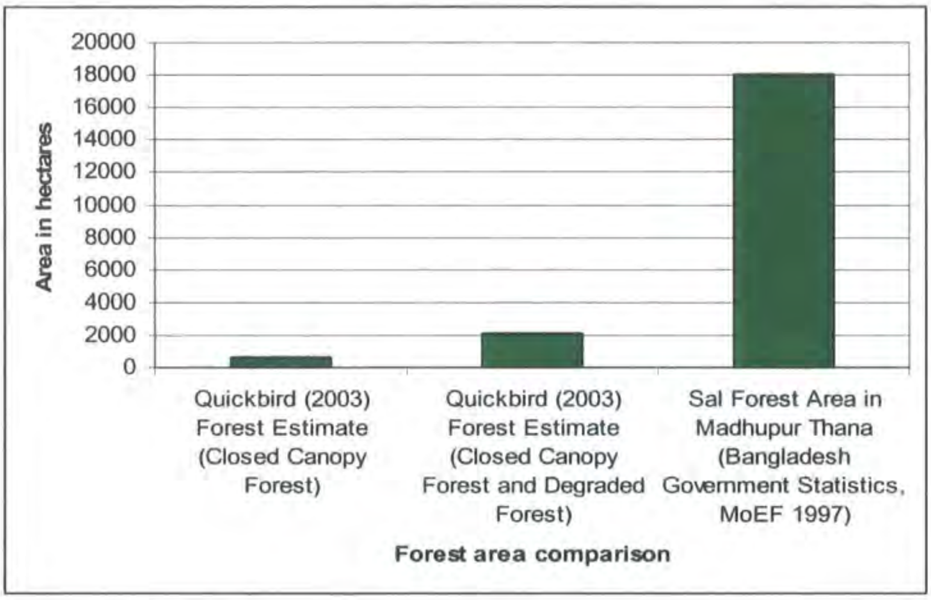


Figure 19. Land cover comparison with government statistics.

The second component of the chapter focused on methods for determining the quality of the remaining intact forest in the study area. Field experience suggests that the remaining forests in Madhupur have been subject to selective logging for years whereby large mature trees are removed from the forest patches. This extent of this practice is not known either in terms of its spatial extent but also its effect on the overall quality of remaining stands. This type of *in situ* quality degradation is normally very difficult to identify in tropical areas when the deciduous forest appears to have full canopy cover.

It is interesting to note the apparent correlation between the spectral data from the fine spatial resolution Quickbird satellite data and field measured structural variables such as tree height, dbh and basal area. The field data give a precise and unbiased picture of forest quality from a structural perspective. The variables dbh, tree height and basal area are correlated with Quickbird bands 2, 3 and 4. Basal area might be treated as a direct measurement as it contributes to canopy density, which in turn may impact on reflectance. A recent study showed that the partial harvest of conifer forest in the pacific northwest of the USA was detectable from Landsat SWIR bands (Healey *et* al. 2006). This agrees with a previous study by Olsson (1994) in Sweden that emphasised the value of SWIR bands in Landsat data for detecting partial canopy removal. Many authors (Horler and Ahem 1986, Spanner *et* al. 1990, Olsson 1994) have attempted to correlate multispectral reflectance data with forest stand variables though none these studies were carried out in the tropics. Authors argue that total reflectance range of forest plots is greater in the SWIR than at visible wavelengths and there is less atmospheric scattering and more shadowing. Franklin (1986), Danson (1987), Danson and Curran (1993), Gemmel (1995), Puhr and Donoghue (2000) demonstrate that relations between near infrared (NIR) and forest structure in conifer forest area weak and this is also apparent in the Sal forests where the NIR (band 4) of Quickbird shows little correlation with forest variables probably because understorey vegetation reflectance tends to dominate the signal. Band 3 of the Quickbird imagery shows the strongest correlation with forest structural variables. All bands in both the visible region and NIR of Quickbird imagery are better correlated with forest structure compared to similar Landsat ETM+ bands. This might be due to its finer spatial resolution where reflectance values better represent forest canopy.

Fine spatial resolution Quickbird imagery, in this context, shows promise for the assessment of forest quality in sal forests in Bangladesh. Fine spatial resolution satellite image, that also includes other satellite sensors such as Ikonos and Orbview, provides an opportunity to reassess the capabilities of satellite remote sensing for detailed vegetation mapping (Mehner 2004). In this study, Quickbird data showed considerable potential as the data were relatively easy to interpret and to match pixels to forest canopy. The study also shows that medium resolution multispectral data is poorly correlated with forest quality (Foody *et* al. 2001). On the other hand, the major problem with the new fine resolution imagery is that its spectral coverage is limited to the visible and near-infrared spectral range. This misses information from shortwave infra-red (such as Landsat TM, ETM+, SPOT 4 HRG) which appears to give the best discrimination between vegetation types (McMorrow and Humes 1986). Sometimes, high resolution satellite image receives signals from undergrowth and this contributes to the reflectance. Crown shadow is another effect, that for larger tree canopies can be seen in the fine resolution data. If a large number of classes are included in the classification, it is likely that mis-classification will occur as a result of mixed pixels, which consist of spectral characteristics of several species and therefore classes (Mehner 2004).

The forest variable prediction map (figure 16) is presented as an indicator of forest quality. Visual inspection suggests that this map based on forest variable (i.e. dbh and height) appears to contain useful information. Furthermore, it corresponds well to the

Quickbird forest classification map but still there might be some confusion. Because, only 5 X 5 metre sample plots were used for this study which might not be fully representative of the tree species in the area. In addition, optical sensors can not capture information directly about biophysical variables such as dbh and height based on canopy reflectance. However, the correlation analysis suggests that these variables might have an impact on canopy cover/density. It can, therefore, be said that athough dbh and height are indirect measurements, in these sal forests where the species distribution is relatively simple; they may be useful in guiding assessments of forest quality. Tree density and basal area seem to have a direct impact on the compactness of the canopy and extent of canopy cover. Further work is needed to establish what effect these variables have on canopy reflectance characteristics.

Remote sensing has a valuable role in forest assessment, particularly in this area where field work is difficult and dangerous and local officials are uncooperative and even hostile. Violence between local people and forest department (resulted in killings of two people during my field work) also necessarily limit the nature and scope of field work that it is possible to carry out. All these factors indicate the value of extracting as much information as possible from remote sensing. For these reasons, forest sample plots could not be larger than approximately 5 X 5 metres. Nevertheless, the results of this study show some promise and suggest that further work is needed to better understand the relationships between satellite data and forest quality. At this stage, the results provide a strong indication that some areas though to be intact are in fact severely degraded. The maps provide a data set that can be tested and evaluated on the ground. The method could, potentially save time and money and enhance the information about Bangladesh forest resources.

Accuracy of the approach was not a major concern in this study rather it intends to demonstrate the temporal change and current forest condition in order to put the issue in the context of socio-political processes that caused deforestation and quality degradation (discussed in later chapters). Results derived from remote sensing gives answers to the 'where' questions (McRoberts and Tomppo, in press) with a strong indication of the pattern of change. However, it does not provide answers to the "why" questions that underlie the reasons for change. This thesis intents to respond on 'why' question using the social science method 'political ecology'.

Although not linked directly to the science, there is strong evidence from Europe that Earth observation can have an effect if local people are aware that forestry and agricultural activities are being monitored from space. This indirect effect may help to conserve valuable forest resource. It can be said that monitoring tropical deforestation using remote sensing techniques may also contribute in the change of attitude of the actors (who are responsible for deforestation) as they may know that their activities are tracked by nongovernmental, academic, private sectors (Fuller 2006) what was absent in earlier times of regular and organised monitoring programmes. Thus remote sensing techniques may have implications for good governance in tropical forest resource management as well.

6.15. Conclusions

It is shown that remote sensing data (i.e. Quickbird, ASTER and Landsat ETM+) can be used to quantify and map forest land cover change in the study area. Quickbird and ASTER data shows particular promise to fill the information gap in forest resources assessment in Bangladesh with a good level of accuracy. On the other hand, historical satellite images provide an excellent resource to help assess land cover change over the last forty years. The methods and results of this study may help government agencies in Bangladesh to improve their statistics as the current government estimate of deciduous sal forest of Madhupur thana is 18,000 hectares (MoEF 1999) whereas this study shows only about 600 hectares of good quality intact forest left in the area. Even if the areas of degraded forest and cleared-out areas are added with the good quality forest, the total area appeared to be about 2500 hectares which is still far behind official government estimates. There is very little scientific research conducted on Bangladeshi forestry. The result is a considerable lack of knowledge about the true state of the resource that makes policy and decision making difficult for the key stakeholders (foresters, politicians and the general public). This absence in research activity, on the other hand, helps tree-pirates, corrupt officials/people to continue their illegal activities. In that respect this study, might help policy planners to respond appropriately with the aid of quantitative information regarding the delicate deciduous forest resources in the central part of Bangladesh.

This chapter discussed the forest change detection issues, mapping and measuring the forest structural variables, to improve our understanding of the condition of sal forest in Madhupur. The next chapters will focus on the human dimension of the problem like local dynamics, problems arising from poor governance (in terms of policies, implementation of projects and lack of accountability of the state authorities etc.) based on the theoretical understanding of political ecology. These discussions may lead to an understanding of why the conditions of the forest have become so degraded over the past few decades. The intension of using remote sensing techniques along with social science methods in this study is to provide clear evidence to the policy planners/researchers/forest professionals about the status of the natural forest resource so that appropriate measures can be taken for its protection/regeneration and to make an justification for an integrated approach to handle natural resource management problems in a third world country like Bangladesh.

Chapter 7
Local Dynamics and Fate of Forest in Madhupur: Political Ecological Explanation

7.1 Introduction

The root causes of forest conflicts (in ecological, economic and ethnographic terms) in different South and South East Asian countries have common features (Colchester 1994; Bandyopadhyay and Shiva 1987; Bryant 1993, Bryant *et* al. 1993, Rigg 1991, Lohmann 1991). Like other tropical Asian countries, the forestry sector of Bangladesh bears the marks of imprudent policies, land tenure problems, the forced expulsion of indigenous peoples and the introduction in their place of new settlers of favoured ethnic groups, the denial of customary rights, a notion of institutional approach, revenue-oriented management techniques and widespread corruption. Considerations of the political sources, conditions and ramifications of these factors may enable a new line of thought. What is termed by Bryant *et* al. (1993) a *paradigm shift* is necessary for resolving eco-conflicts in Bangladesh forests. The influence of capitalism and current globalization, both having elements of postcolonialism, are often blamed as major causes of deforestation/natural resource depletion in the third world (Escobar 2004, 1995, Peet *et* al. 2004). In addition to capitalism and materialism, Gadgil and Guha (1995) more aggressively blamed the 'modern western patriarchal science' for environmental fragility in the developing world. But some political ecologists are careful about admitting these claims/causes of deforestation as Bryant and Bailey (2000) in their book 'Third World Political Ecology' stressed that it is too early to be certain. Accordingly in Madhupur, local and national level dynamics are more important factors than global forces though the latter are not absent. Together these have led the sector towards its present point of dysfunction.

Revenue-orientated forest management methods have been practised in Bangladesh since the first forest policy was introduced in 1894 by the then British Government. Afterwards the forest policies of 1955, 1962, 1979 and 1994 echoed the same principles. The attitudinal/conceptual shortcomings of these forestry policies, and thus the state of the forests, in the Indian sub-continent have been examined by a number of studies (Gadgil 1983; Guha 1989; Poffenberger 1990; Khan 1998; Sivaramakrishnan 1999). However, there was a slight shift in the 1994 forest policy of Bangladesh, where the government aimed for social development through the forestry sector, though there was no clear indication of how to achieve the goals set (Khan 1998). This was tuned to the forest component of the Rio Conference in 1992. But the four Rio principles of sustainability – that basic needs of local people must be met; that resources should be under local control; that local communities must have a decisive voice in planning; and that locals should represent themselves through their own institutions (Colchester 1994) - are as far away as ever, as I found through my field investigation in the Madhupur sal forests. In fact the government's move for social development through community forestry, which was aimed at rural poverty reduction, not only fell short of its target but also created a multi-dimensional social and ecological crisis in the study area.

In this chapter I will investigate the context of environmental change and the causes of conflict, following a political ecological approach. I will examine land tenure problems; the practice of power in shaping the fate of forests; the economic needs of locals and their impact on natural resources; and the prevailing corruption and mistrust in the Madhupur forest. I will also focus on the people in the woods (their status, need, desire, choice and participation), other different actors, the historical roots of present-day antagonism, and the resultant social movements of the forest community. This area-specific investigation of socio-ecological conditions and relationships (Bryant 1992) will be useful to gain insights into how contextual actors impinge upon the state of forests in Madhupur, particularly their making of the fundamentally different environmental condition that Ulrich Beck (1991) has termed the 'risk society'.

7.2 Demography and Population Flux in the Madhupur Sal Forest

7.2.1 Demographic Characteristics

A total of 150 families were surveyed in the study area to know about their dependency on forest resources, their daily interaction with nature, the land tenure problems in the area, their mode of subsistence, the nature of resource depletion, and the conflicts and resentments that have pushed them towards protest. Among the respondents, 68 are Bengali and rest were taken from tribal communities, 69 Garo and 13 Koch. The sample population was drawn from five mauzas surrounding the Madhupur sal forest. The surveyed villages are located in the interior part of the National Park area. The Bengali families are found in the periphery areas of the forest while the tribes are mainly located inside the forest. I tried to maintain a balance in selecting respondents but this was not always possible as the intention of the survey was to include areas (and families) that are adjacent to the forest boundary. As a result, Aronkhola mauza (table 1) received more attention than others in the household survey. Out of 150 family heads who responded to the semi-structured questionnaire, 121 males and 29 females were consulted.

The Bengali communities are mainly Muslim by religion, while the Garo tribes are Christian. The Koch people (locally khown as Hazong) follow the Hindu religion and are mixed with a few Bengali Hindus, although this latter group are not recognised by their mainstream co-religionists. The Bengali families are male-dominated, while the tribal families are matriarchal. The tribal families have adopted many Bengali customs, as they have been living here for generations.

The family size is comparatively large for both Bengali and tribal families. A total of 934 people are covered in the survey, with an average household size of 6.2 (figure 1). A number of joint families were found, with most in single units, as defined by food intake from the same kitchen, but little emphasis was put upon these statistics in the

Table 1 – Mauza wise respondents.

		Mauza					Total
		Aronkhola	Beribaid	Chunia	Gachabari	Pirgacha	
Ethnicity	Bengali	41	8	0	16	3	68
	Garo	8	16	14	15	16	69
	Hazong	8	4	0	0	1	13
Total		57	28	14	31	20	150

Source: Author's questionnaire.

survey. Almost fifty percent of the interviewees are in the age group 20-40 and they tend to be the key person in their families in terms of income generation and decision-making. The age distribution of the surveyed people fits fairly with a normal Q-Q line (figure 2), which means that age of the respondents is almost normally distributed. Life expectancy is relatively high in the area, with 32 respondents above the age of 60 (16 Bengali, 16 Garo). This may be because of their hard working and simple lifestyle and healthy food habits.

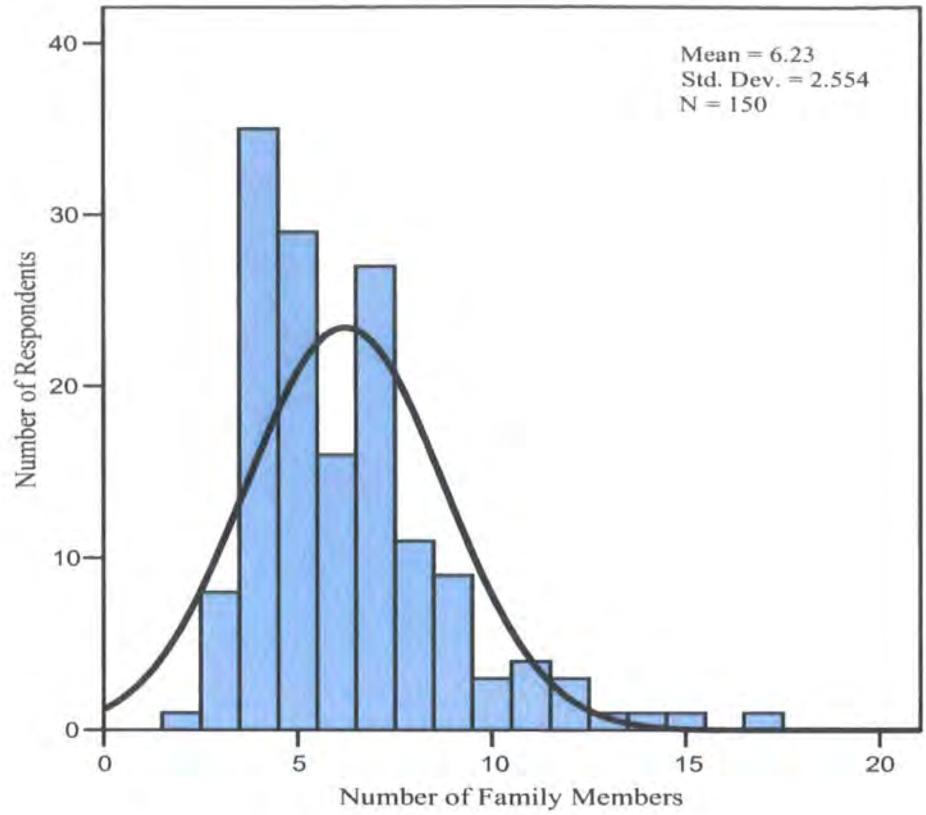


Figure 1: Family size in the study area.
Source: Author's questionnaire.

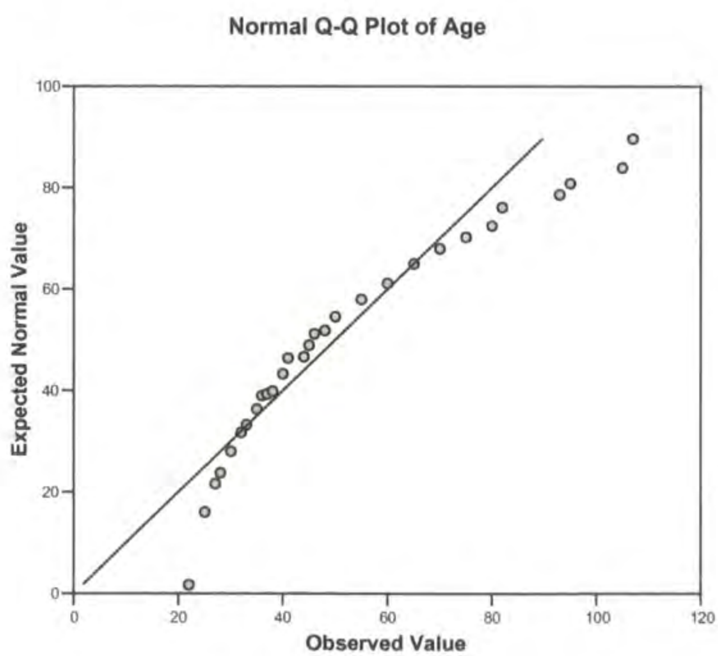


Figure 2: Normal Q-Q plot of age
Source: author's questionnaire.

7.2.2. Immigration and Emigration in Madhupur Forest Area

Most respondents had little idea of the settlement history of the forest area. All they have are local legends. From the Garo's point of view, they have been living in the area for hundreds of years but this claim is opposed by the government agencies who call them illegal occupiers. On the other hand, the Bengalis, although most have migrated here in recent years, have been given permanent resident status. Majumder (1906) wrote that the area including the forests was ruled by the Buddhist Pala kings (8^{th}-11^{th} century) but there is no firm evidence of occupation beyond some old ponds and ruins (Sachse 1921). According to Sachse, the jungle then was characterised by thick tree cover, with water available, and the adjoining villages were thickly populated. He saw the aboriginal tribes like the Garo, Koch and Hajang as "pioneers of cultivation" in the area. Khaleque (1987) speculates that the Garo people might have settled in Madhupur forests sometime in the middle of nineteenth century, based on a supposition of the anthropologist Nakane (1967) that the Garo people living in the northern parts of Mymensingh district may have migrated at this time from the interior hills of India. Due to a scarcity of land for cultivation and increasing population in the hills, some Garos moved to the southern slopes of the Garo Hills, what is now the Madhupur tract.

If Burling's (1985) argument based on the distribution of languages is taken into account, it can be said that the Garo settled in Madhupur forests much earlier than the period speculated by Khaleque and Nakane. Burling thinks that speakers of the Bodo sub-group of Tibeto-Burman languages now found in certain pockets up and down the Brahmaputra valley are the remnants of languages that once covered a much wider territory (Burling 1985). According to him, the Bodo language group, which includes the Garo language, could have been spoken not only in what is now the Garo Hills of India, but also in the Brahmaputra valley to the north and even in the lowlands to the west and south. Then the Indo-Aryan ancestor language of Bengali and Assamese began to move in and separated different groups of Bodo speakers from each other. The Madhupur forests may be considered as one of those residual pockets of Tibeto-Burman speakers mentioned by Burling. If this pocket is taken as the remnant of a language area that once covered the wider territory mentioned by Burling, then it may be argued that the Garo have been living in Madhupur forest for more than a thousand years (Khaleque 1987). However, there is a lack of documentary proof of the settlement of Bengali people in the forest.

Discussion with some Bengali key informants revealed that Bengali settlement began from about 1900 when settlements were encouraged by the Zamindars, landlords who were entrusted by the colonial government to collect revenue. A large-scale Bengali immigration followed, especially in the periods when many Koch and Garo families emigrated to India due to state partition (1947), the Indo-Pakistan war (1965), and the liberation war that led to the independence of Bangladesh (1971). Most Bengali settlers came due to a shortage of land in their natal villages, which are located in the plains area surrounding the forest.

Bengali respondents mentioned that their settlement in the area is recent, with the earliest claim being 60 years ago. Table 2 enumerates the causes given by Bengalis for their presence in the forest. 17 said that they migrated for economic betterment and 25 mentioned that their ancestors had migrated here. A few (labelled as others in the table) mentioned the government's khas land (untitled public land) allocation scheme, marriage purposes, and torture (claimed by the Hindu migrants) by Muslims elsewhere as the cause of their migration into the forest area. No-one in the Garo community argued that economic development was their reason for living in the area, although it is interesting to note that out of 69 Garo respondents, 60 were unwilling to answer this question.

Table 2: Cause of Migration of Forest Dwellers.

		Cause of Migration				Total
		Ancestral Migration	Economic Development	Not Responded	Others	
Ethnicity	Bengali	25	17	23	3	68
	Garo	2	0	60	7	69
	Hazong	5	4	4	0	13
Total		32	21	87	10	150

Source: Author's questionnaire

7.3 Socio-Economic Status of Forest Dwellers

7.3.1 Employment Status

Farming is the main source of employment for the majority of adults in the area. Males in Bengali families are occupied in agriculture and both male and female members of tribal families are farmers. More than sixty percent (table 3) of the heads of the households are farmers. Pineapple, banana and papaya gardening, cultivation of different spices, and wet rice production are the main activities. With the exception of the tribal families, all the adult female members in Bengali communities do household work. The women of the tribal families do both household work and farming jobs. The household work includes cooking, cleaning, homestead gardening, care of children and livestock and crop processing. One of the major tasks of the females is to collect firewood from the forests for their household consumption and sometimes they

Table 3: Occupation of Forest Dwellers.

		Ethnicity			Total
		Bengali	Garo	Hazong	
Occupation	Agriculture	49	45	12	106
	Household job	2	5	0	7
	Service	4	11	0	15
	More than one job	5	6	0	11
	Business	8	2	1	11
Total		68	69	13	150

Source: Author's questionnaire

Figure 3: Roots of wild plants (upper left) collected from Madhupur forest. Cash crop (banana and pineapple) and paddy is the mainstay cultivation in the area. Dry leaves are collected (lower left) to carry to villages and the market (lower right). Source: Author.

sell it to local businessmen for urban consumption (figure 3). It is imperative to mention that 40% of the energy consumption in the urban areas still depends on wood biomass (Bangladesh Forest Statistics 1999). Some of the male heads of household run small businesses in the village markets, some are drivers of rickshaws and pedal vans, and some work as day labourers in the fields of medium or large farmers.

Both male and female members of the tribal communities are sometimes interested to undertake off-farm activities like selling poultry, fruit and vegetables that they produce or gather in the natural forests, and agricultural inputs in the market nodes.

Table 4: Occupation of Forest Dwellers by Mauza.

		Occupation					Total
		Agriculture	Household job	Service	More than one job	Business	
Address	Aronkhola	44	3	2	3	5	57
	Beribaid	20	1	2	4	1	28
	Chunia	11	0	2	1	0	14
	Gachabari	17	3	6	3	2	31
	Pirgacha	14	0	3	0	3	20
Total		106	7	15	11	11	150

Source: Author's questionnaire

There is spatial variation of the occupation distribution in the study area. Table 4 shows that people from Aronkhola mauza are more economically active than those in other mauzas. This is because of the comparatively better infrastructural facilities, especially the road network, and natural resource availability in Aronkhola mauza than in the other three.

7.3.2 Education

The overall story of literacy in the area is very poor. About 45 per cent of respondents claimed that are either illiterate or only able to sign their name and identify numbers and letters. Of the rest, 29 per cent have only primary level (reached 1st to 5th grade) education, and the rest have reached or completed secondary or post secondary level education (26 per cent).

Table 5: Status of Education in the Area in Relation to Occupation.

		Education					Total
		Illiterate	Primary	Secondary	Higher Secondary	Higher Degree	
Occupation	Agriculture	53	36	15	2	0	106
	Household job	2	1	4	0	0	7
	Service	2	2	4	4	3	15
	More than one job	7	2	2	0	0	11
	Business	4	2	5	0	0	11
Total		68	43	30	6	3	150

Source: Author's questionnaire.

Table 5 shows that people engaged in agriculture are mostly illiterate or educated up to primary level. This low literacy rate in the Madhupur forest area forces people to stay with their ancestral profession and rely on forest resources for their livelihoods. The literacy rate is comparatively high among the young male population, however, especially among the Christian Garo. Local Christian charities are contributing a great deal to educating the tribal people in the area. According to the informants, the drop-out rate from the school is high when boys are ten to twelve years old and are able to participate in the agricultural activities of the household. The poorer households do not have the resources to hire labour for agricultural activities and therefore have no other option. Even in the relatively wealthier households, this is done in order to save the resources that would be required to hire labour. Girls are taken out of school during their teenage years, and sometimes before that for marriage. This trend is more or less same among in all three ethnic groups.

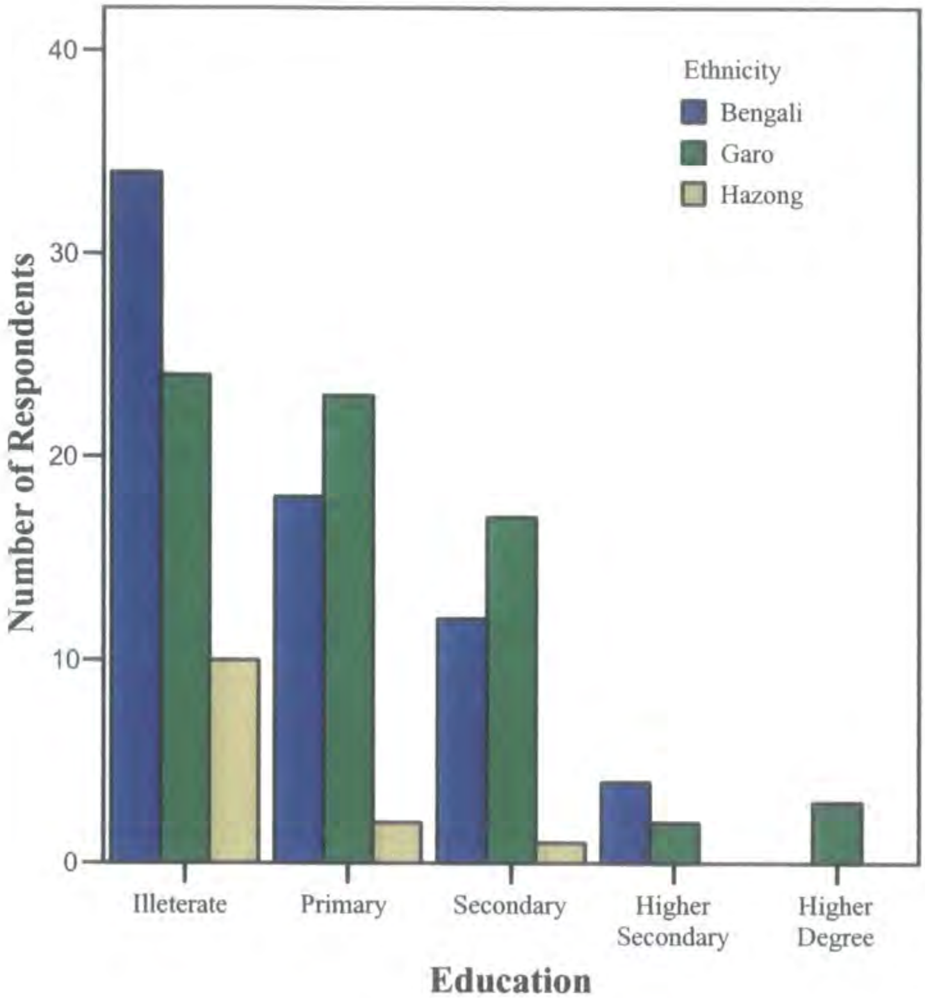


Figure 3: Level of Education of Respondents by Ethnic Group.

Source: Author's questionnaire.

7.3.3 Land Occupancy of Forest Dwellers

The survey results show that about half of the households have been living in the area for more than 50 years but the respondents could not provide any supporting evidence because they are mostly illiterate and do not have any documentary records. They hold agricultural and homestead land without any legal title deeds.

About 90 percent of the sample households have their own cultivable lands and the average farm size is 2.30 hectares, with a household land holding of 1.83 hectares. Among the respondents are a small number of families (10) with large holdings of 10-20 hectares but the majority (about 70%) occupy medium size farm and homestead lands.

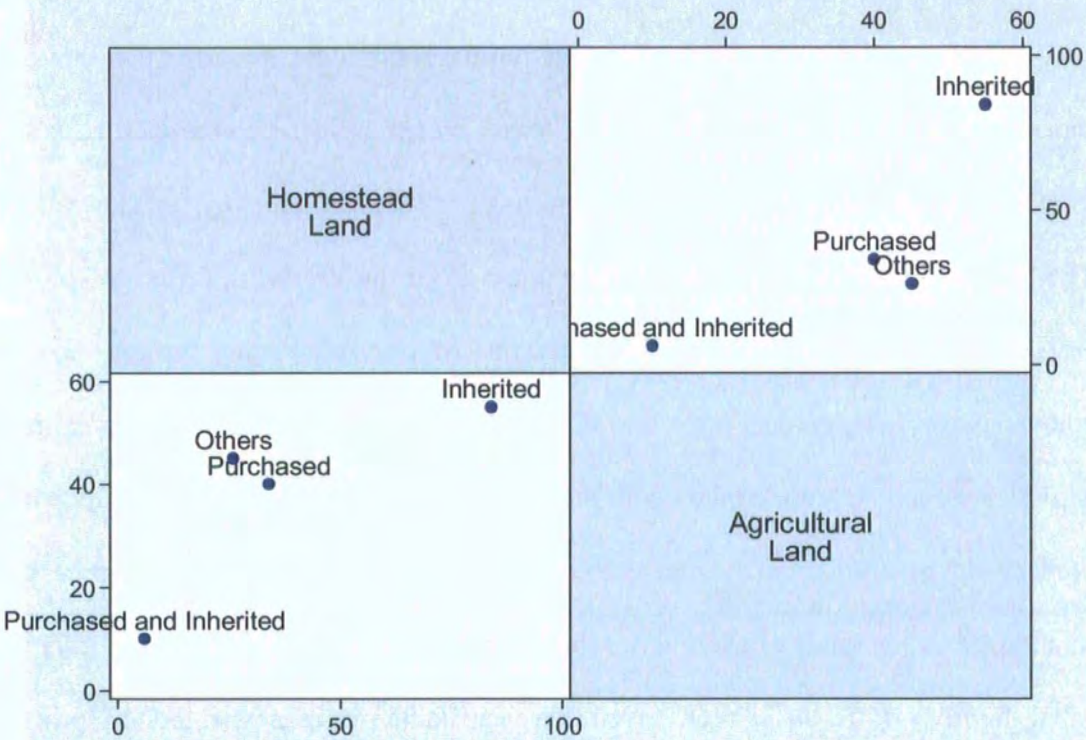


Figure 4: Matrix of Land (homestead and agricultural) Inheritance.

Source: Author's questionnaire

Five percent of families hold Khas lands from land revenue department of the government. More than 70 percent of the respondents mentioned that they have inherited their homestead lands (mounds locally called chala lands) while the others reported that the lands they occupy are leased, captured or purchased. The same is true for their agricultural (low lying byde) lands. The matrix (figure 4) shows that there is an analogous pattern in agricultural and homestead land inheritance. Most of the respondents who received homestead lands from their ancestors or had purchased it or acquired them by various other means (khas land distribution, illegal capture), did the same for their farm land. As noted above, most landowners do not have any legal documents of land ownership. This is because the existing tenurial problem is very complicated and uncertain in the area, but the respondents reported that they still transfer the land ownership (buy, sell or lease) on the basis of communal trusts and mutual understanding and that this system has prevailed sustainably for generations. The farmers keep their lands under cultivation all of the year with different kinds of crops. The major crops are different varieties of rice, pineapple, banana, papaya, cotton, pulses, sugarcane, jute, etc (figure 5). In most cases all of the farming activities are manual, undertaken with the help of family members. These include land preparation, planting, maintenance, harvesting, post harvest operations and processing. In addition to the lands already under their possession, some of the Bangali (27) and tribal families (30) have been given ten-year land occupancy rights to practise agroforestry and 25 year rights for woodlot plantations by the forest department. According to these schemes, the holders can use this land and enjoy its harvests as proposed in the forest department's project plan.

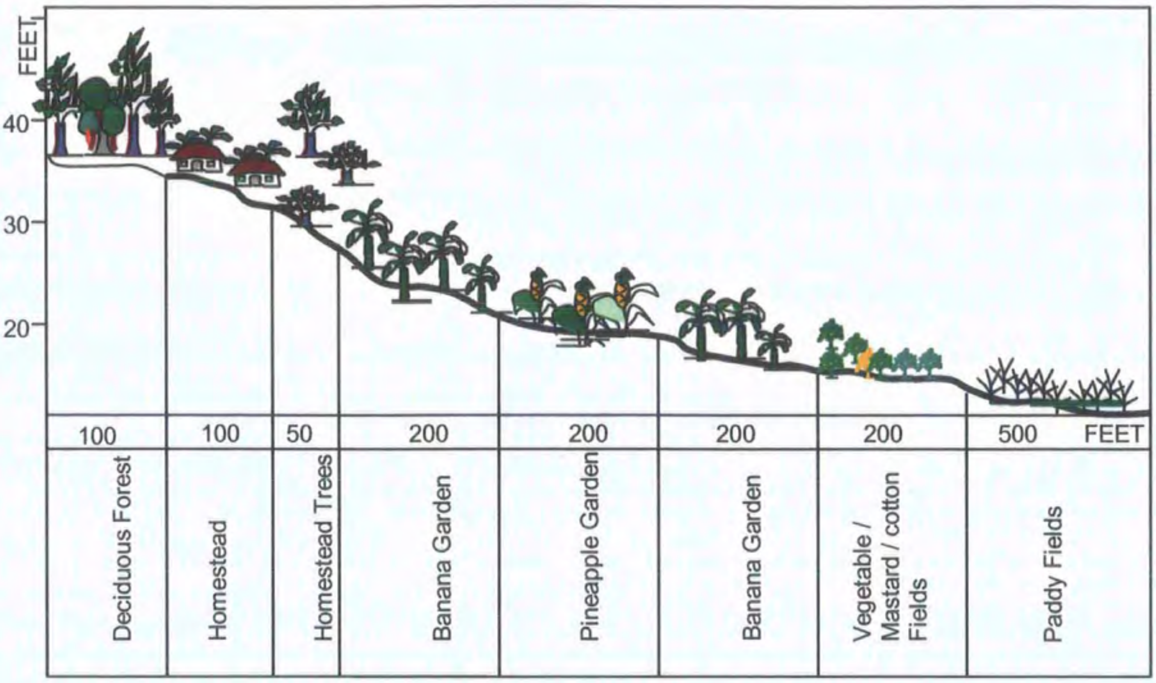


Figure 5: Cross Sectional Diagram of Sal Forest (not to scale).

7.3.4 Earnings

It is very difficult to get information about the income of people in rural Bangladesh as they are very reluctant to answer such questions and anyway they treat the word income as cash savings (after meeting all expenditure). Thus rice and other subsistence crops grown and consumed by the household members are not considered as income. This also holds true for money earned by a household selling pineapples or other cash crops. Wealthy households that are able to save cash are also unwilling, so questions regarding income were dropped from the questionnaire and observation and discussion with the key informants was employed instead to understand the economic status of respondents.

The average monthly household income in this area is around 2500-4000 taka (equivalent to £20 to £35)[1]. This is around the current national poverty line (3700 taka or £37 per month). The income is mainly based on agricultural activities: work as daily farm labourers, rickshaw or van driving, and small business. Some people are generating income by selling forest products (fuel wood, vegetables like wild potato, medicinal products, etc).

7.4 Forest Resources and Communal Dependence

The sal tree is the dominant variety in Madhupur Forests. There are some patches of mixed forest scattered throughout the belt that have few sal trees, and some have none at all. In addition to sal trees, the other main tree associates are koroi (*Albizzia procera*), jogini charka (*Gmelina arborea*), kaika (*Adina cordifolia*), sidah (*Lagerstroemia parviflora*), bazna (*Zathoxylum budrunga*), sonalu (*Cassica fistula*), ajuli (*Dillenia pentagyna*), gadila (*Careya arborea*). The common undergrowth is swati (*Pennisetum setosum*), while the common climbers are mongolia lata (*Spatholobus roxburghii*) and kumaria lata (*Smilax macrophylla*), sungrasses (*Imperata arundinaea*) and thatch grasses (*Arundineacea cylindrica*) grow throughout the forest (Chowdhury 1957).

[1] This compares with Tk 21,000 (£210) estimated by Khaleque (1984).

Figure 6: Natural sal forest with thriving biodiversity (upper left), single species (rubber) plantation with limited forest products for the community (upper right). Natural forest is replaced by plantation schemes like agroforestry (both in the bottom). Source: Author.

Various products of this rich forest biodiversity (figure 6) are in demand by forest-dwellers and city-dwellers alike. The sal is the most important tree species of the Madhupur forest, a statement that was supported by almost ninety per cent of respondents. According to them, sal tree poles and sawn timbers are used in house building, for which there is an unlimited demand across the country. This species is a very heavy hardwood and is not generally used for furniture making. Like the sal, all of the other species mentioned above are used for house building but most are used for furniture as well. The respondents mentioned that most of the trees are useful to them for different kinds of purposes; they use hardwoods of sal, koroi, kaika for making the wooden parts of agricultural implements, bullock-cart wheels, axles as well as pedals for husking (ESRU 1992). Some species, like jogini charka are preferred for planking. The survey showed that eucalyptus trunks are not so versatile; they are utilized as poles but they are not as long-lasting as mature sal trunks. This species is not good from ecological perspective as eucalyptus is believed to poison the soil and lead to a lowering of the ground water table (Bandyopadhyay and Shiva 1984). There is a concern among the villagers, NGOs and charities about this adverse environmental effect. Trunks of ajuli trees are commonly used for making house frames and roofing skeletons. These diversified resources are shrinking as natural forests are converted into monoculture (rubber plantations) or replaced by other landuse patterns (figure 6).

According to the findings of the Bangladesh Energy Planning Project (BEPP 1984), the country's total biomass fuel production was estimated at about at about 35 million tons per year for 1980/81, of which fuel wood contributed 12.4 percent, against 66.4 for crop residues and 16.1 percent for animal dung. Of the total fuel wood energy supply, state forests and village forests contributed 17.1 and 70.8 percent respectively (Ghani 1990), but areas close to the forests use fire wood more intensively than other sources of energy because of the immediate availability of trees. In the Madhupur forest, people collect fire wood not only for their household consumption but also to supply the nearby brick yards, and the urban areas (i.e. the nearby districts, Tangail and Mymensingh) for cooking in the households and restaurants.

Table 6: Fuel Use Estimates in Bangladesh.

End Uses	1989-90	1994-95	1999-2000
Urban cooking	76.4	94.8	107.2
Rural cooking	374.5	382.3	376.8
Industry	104.3	119.3	138.5
Commercial	2.3	2.3	2.3
Total PJ[1]	558.1	598.7	624.8
Million tonnes of fuel	36.9	39.5	41.2

[1] (All figures in Peta Joules, 1 PJ = 10^{15} Joules)
Source: Bangladesh Energy Planning Project 1984, cited in Ghani 1990.

People in Madhupur forest, in particular, collect small twigs, chips of bark, branches, and decayed branches as firewood for their household consumption and for selling in the markets (plate 3). Fuel wood from this forest is in great demand in the cities as well. Even dried climbers and leaves are used as fuel. Almost 100 percent of respondents mentioned that the forest is the prime and only source of their energy, and 90 percent of them collect firewood, dry leaves and branches for their household consumption. The remaining ten percent rely on hired people for fuel wood collection. It is very interesting to note that 121 respondents (eighty percent) claimed that they do not collect any product from forests for sale. This contrasting response pattern (revealed in table 7 and 8) was because these forest dwellers assumed that they might be reported to the forest department, who consider fuel wood collection from forests as theft.

Women and children are most active in collecting twigs, dry leaves and branches in the forest, while men are involved when they are needed to fell trees and to carry heavier bulks out of the forests. The respondents mentioned that they (mainly women) hire a rickshaw van to carry their harvest when it is too heavy to transfer as head loads or when they find that the fare can be shared by other fellow collectors.

The roots of a number of herbs and creepers and wild fruits and berries in the Madhupur forest are edible and provide sustenance to the local people. Tribal communities are more active than Bengalis in collecting these products for their consumption and to sell in the markets. Sungrasses and thatching grasses are widely used by people for constructing the roofs and walls of thatched houses in the villages

Figure 7: Tree branches collected for selling (upper left), logs transferring by local vans (upper left). Wood logs theft by timber merchants (lower left) and tree stealing by a Bengali local man (lower right).
Source: Author

Table 7: Support of Forest Products for Household Need Fulfilment.

		Role of Forest Products for Household Needs					Total
		Only firewood collection	Firewood and one other material collection	Firewood collection and two other support	Firewood collection and three other support	Not taking any support from forest	
Ethnicity	Bengali	16	13	11	22	6	68
	Garo	23	13	8	20	5	69
	Hazong	2	5	2	2	2	13
Total		41	31	21	44	13	150

Source: Author's questionnaire

Table 8: Forest Products Collection for Sale.

		Forest Product Collection for Sell				Total
		Fruit/ Vegetable, medicinal plant	Firewood	Medicinal plants	Nothing for sale	
Ethnicity	Bengali	6	4	2	56	68
	Garo	1	3	5	60	69
	Hazong	0	0	0	13	13
Total		7	7	7	129	150

Source: Author's questionnaire

within and outside the forest areas. Even the wealthier families use these grasses for constructing their kitchens, sheds for domestic animals and other out buildings. Grasses other than thatching and sungrasses are an important source of fodder for the livestock of local people.

Some products of this forest have medicinal values, including basak (*Adhatoda vasiu*), kalamegh (*Audrographis paniculata*), satamul (*Asparagus racemosus*), swarnalata (*cuscuta reflexa*), sarpagandha (*ranwolfia serpentina*), etc. The local population is a vast storehouse of knowledge of herbal medicines, which has been passed down the generations. They collect nuts, bark, gums, leaves, roots from different species of trees and herbs and process them through indigenous methods for the treatment of various ailments such as lack of appetite, indigestion, dysentery, worms, asthma, rheumatism, etc. Table 9 gives a detailed list (after ESRU 1992) of the different use of tree species of the Madhupur sal forest. A few respondents mentioned that they collect these plants of medicinal value to sell to pharmaceutical companies but most do it only for their private use. Women are especially active in collecting these plants from forests. Middlemen or agents purchase the products from the locals and bring them to the urban drug companies. However, the products of forest biodiversity have been squeezed very much in recent times as most of the forests have been cleared out within a very short span of time. Use of remote sensing techniques provides clear evidence of natural resource depletion (for details see chapter three). Many political ecologists have also used this remote sensing technique (Eastman *et* al. 1991, Turner *et* al. 2001) to show the destruction of natural forest resources and as a result the breakdown of resource base of the rural community. Turner *et* al. (2001) added local history with remote sensing techniques to show a complex picture of land cover change in Yucatan. Eastman *et* al. (1991) while portraying land degradation, used oral history, written records, and other supporting documents as supplementary to remote sensing.

The forest lands are also used, in Madhupur, by the local people for agricultural activities (Amads 2003). Sometimes people from distant places take lands upon lease and use it for paddy or other types of cash crops (pineapple, banana, ginger, turmeric

Table 9: Usefulness of Madhupur Forest Products.

Name of Tree	Tree Products Used	Nature of Use of Tree Products	Remarks
Sal (Shorea robusta)	Trunks, twigs, leaves, stem, gum.	Trunk: Furniture, poles, plough. Twigs, leaves and stems: fuel	Both domestic and commercial use.
Amloki (Phyllanthus embelica)	Twigs, leaves and fruit.	All three elements are used as an appetiser; also used as raw material for Ayurvedic medicine.	Both domestic and commercial use.
Boyra (Terminalia belerica Roxb.)	Twigs, leaves and fruit.	Twigs and leaves: Fuel. Fruit: Antidote for worms, raw material for Ayurvedic medicine.	Both domestic and commercial use.
Haritaki (Terminalia chebula)	Twigs, leaves and fruit.	Twigs and leaves: Fuel. Fruit: Digestion, raw material for Ayurvedic medicine.	Both domestic and commercial use.
Ajuli (Dellenia pentagyna Roxb.)	Trunks, twigs and leaves.	Trunk: House and roofing frame, fuel. Twigs and leaves: fuel, leaves also used as cover for certain horticultural products like ginger, taro, pineapple.	Both domestic and commercial use.
Amra (Spondias pinnata)	Trunk, twigs, leaves, fruit.	Trunks, twigs and leaves: Fuel. Fruit: appetiser, also raw material for Ayurvedic medicine.	Both domestic and commercial use.
Banyan (Ficus religiosa)	Twigs, leaves	Twigs and leaves: fuel.	Domestic use.
Shothi (Curcuma Zeodenia)	Roots	Roots: Barley.	Commercial use.
Joyna (Schleichera Oleosa)	Trunk, twigs, leaves, fruit.	Trunk, twigs, leaves: fuel. Fruit: Oil.	Domestic use.
Moyna (Vangueria spinosa)	Trunk, twigs, leaves.	Trunk, twigs, leaves: fuel.	Domestic use.
Kaika (Adina cordifolia)	Trunk, twigs, leaves.	Trunk: furniture. Twigs and leaves: fuel.	Domestic and commercial use
Polash (Beutea monosperma)	Trunk, twigs.	Trunk, twigs: fuel.	Domestic use.
Shirish (Albizia lebbeck)	Trunk, twigs, leaves.	Trunk: furniture. Twigs and leaves: fuel.	Domestic and commercial use

Source: ESRU 1992.

etc.) cultivation. Only 35 percent of people (mostly tribal communities) agreed that they were farming on the forest department's lands, and they claim that their fields have been occupied by their ancestors for hundreds of years. In reality, the percentage

Table 10: Legitimacy of Agricultural Lands Held by Local People.

		Legitimacy of Agricultural Lands Held by Local People		Total
		Forest Department's land	No Response	
Ethnicity	Bengali	28	40	68
	Garo	14	55	69
	Hazong	2	11	13
Total		44	106	150

Source: Author's questionnaire

of illegal farming is pretty high, as was observed during the survey. However, most of the farmers (80 percent) admitted that they had felled forest trees for extending their fields. The average size of the crop farms located in the chala lands (forest) is 1 hectare. But the main agricultural plots (generally large) are situated in the low-lying byde lands, where wet paddy (local and transplanted varieties) is grown.

7.5 Evaluating People's Participation in Forestry Programmes

Forest resources are playing a vital role in the environment, economy and other areas of livelihoods in Bangladesh as the country is based on a rural economy. Both village forests (including forestry and fruit trees) and the state forests are the sources of supplying people's needs. But the services of the forests to the community have influenced by the prescriptions of foreign donors and the Bangladesh forest department attempts to integrate the Madhupur forest dwellers and other locals into a system of forest regeneration and maintenance. In addition, the forest department has realised their inability to rehabilitate the country's degraded forest lands on their own and they have therefore proposed and implemented social forestry schemes in many parts of the country including the study area. Social forestry is defined by Ghani (1990) in the FAO/UNDP sal forest rehabilitation project plan as "forestry and forestry related activities taken by a homogeneous target group having the same

Table 11: People's Participation in Social Forestry Projects.

		Projects Implemented				
		Agroforestry Project	Not Participated	Woodlot and Agroforestry Project	Woodlot Plantation	Total
Ethnicity	Bengali	4	38	2	24	68
	Garo	5	43	2	19	69
	Hazong	0	12	0	1	13
Total		9	93	4	44	150

Source: Author's questionnaire

socio-economic background and also having common aims, interests and principles, normally on lands owned by any of the Government departments or local bodies". Since the mid-1970s, social forestry has been a movement in international forestry development (Fortmann 1995, 1996; Westoby 1987). Its success is mixed in many parts of the world (Shiva *et* al. 1982, Peluso and Poffenberger 1989, Lee *et* al. 1990) and this is also true for Bangladesh. In Bangladesh some barren lands have been successfully vegetated and local communities have received benefits in northern and southern parts of the country, but in some places social forestry schemes caused deforestation. The Madhupur forest is one of forest department's social forestry project sites where they have implemented agroforestry and woodlot forestry in addition to other schemes like buffer zone forestry, strip plantations and other types of projects related to bamboo, cane, and thatch grass plantation. Agro forestry and woodlot plantations are the two main approaches where local people are taking part and are given temporary tenurial land rights and a share of wood products in different phases of the project. About 40 percent (tables 11 and 12) of the respondents in the survey hinted that they are integrated in the social forestry projects. Two thirds of the respondents have not had

Table 12: Mauza wise Participation of Social Forestry Projects in Madhupur Forest.

		Implementing Projects				
		Agroforestry Project	Not Participated	Woodlot and Agroforestry Project	Woodlot Plantation	Total
Mauza	Aronkhola	3	36	2	16	57
	Beribaid	5	23	0	0	28
	Chunia	0	5	0	9	14
	Gachabari	1	10	2	18	31
	Pirgacha	0	19	0	1	20
Total		9	93	4	44	150

Source: Author's questionnaire.

any involvement in social forestry projects; rather politically or economically influential people of distant places received the project plots. This bias of the forest department towards powerful people causes frustration among the locals and the incomers naturally feel less functional or emotional attachment with the forest. The forest department is supposed to allocate lands for social forestry which is degraded forest or has no forest at all or is unoccupied by the forest department as per the social forestry policy guideline. But sometimes, they clear out good quality standing forests to make room for agro forestry projects as the increase in projects might yield bribes

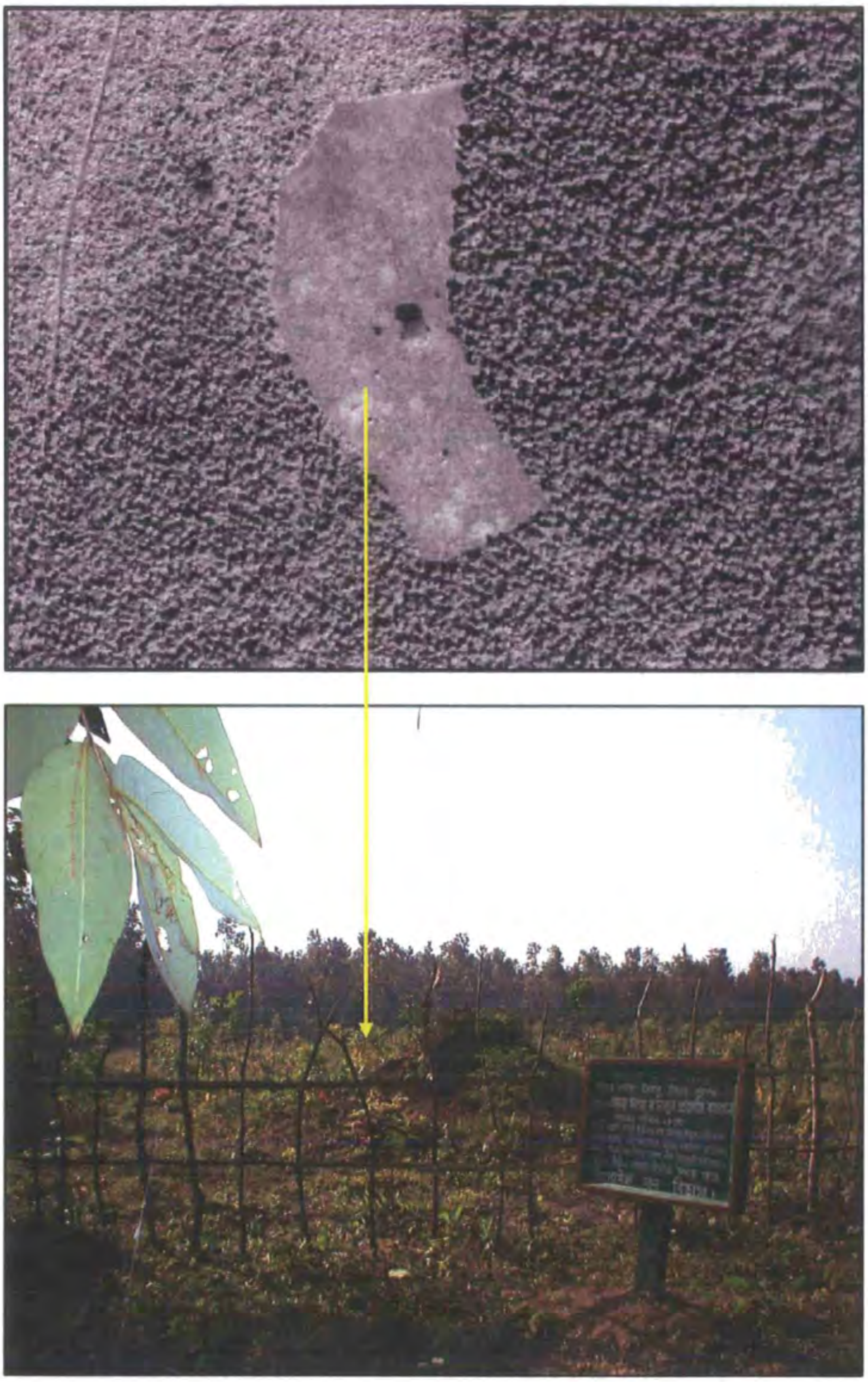


Figure 8: Clearance of standing natural forest (high resolution Quickbird panchromatic satellite image of October 2003, left) for project implementation (right). Both photographs show same particular area.
Sources: left and right, author.

to forest officials. This inference is supported when vacant lands are found (figure 8) surrounded by good quality forests, ready for forestry projects. At this point I should mention that the multi-dimensional corruption of forest officials has been reported in the national newspapers many times (*Daily Ittefaq* 15th February 1998; *Daily Sangbad* 16th February 1998; *Daily Sangbad* 20th September 1995), and even the Environment Minister of Bangladesh has admitted this dishonesty in the forest department (*Daily Ittefaq* 12th July 2003). The most serious case is the recent charge against a state minister, who is alleged to have illegally occupied 558 acres of state forest in Madhupur area in recent times (The Daily Star 10th April 2005). But few cases ever come to trial.

The social forestry plot recipients mentioned in my survey say that they generally raise turmeric, ginger, papaya and different spices on their agroforestry lands. But the selection of the tree species is determined by the forest department and they are mainly the acacia and eucalyptus recommended by the Asian Development Bank. These species are common to many other third world Asian, African and South American countries through the influence of such international financial institutions (Rocheleau *et* al. 1995, 2001; Lohmann 1991). Some respondents said that they do not have an agroforestry plot in their name but they work in these plots as daily labourers. Thirty percent of people (among the participants) hailed the project as a success and said that they received financial (for seedling purchase and maintenance) and wood product benefits from the forest department without any problem while about forty percent mentioned bureaucratic problems and corruption. One of the main aims of the forest department in selecting acacia and eucalyptus for the project is to supply fuel wood for the community because these are fast growing species. But most of the respondents were dubious in responding to my question as to whether this was successful. They commented that native species are much more useful and productive in providing firewood and other products; in contrast, the exotic species are slim and without so many branches and leaves. Another big problem of the project depicted during the survey is, as mentioned earlier, that the agroforestry plots are given to the elite, who do not live in the forest area. Local people allege that the elites are interested in receiving social forestry plots only because of their agricultural products, and they are therefore reluctant to take care of the forest. These local/regional elites maintain close ties with the influential forest officials who are authorised to distribute land. The forest dwellers claimed that the elites do not feel for the forest as they do. However, this ill-management causes a long term threat towards the success of the project and eventually leaves the degraded area as it was or worse.

It was evident in the area that the forest department does not pay sufficient attention to protecting its new seedlings planted throughout their forestry schemes. The field officials are only interested in the plantation phases where financial matters are involved. But they claim that it is the cattle of the forest dwellers that destroy these new plantations as the villagers use the forest lands for pasture. However, it can be said that the social forestry schemes in the forms of agroforestry and woodlot plantations caused further deforestation and made grounds for social tensions in the area.

7.6 Political Ecology of Deforestation in Madhupur Sal Forest

7.6.1 Actors and Actions in the Woods

The actors who shape third world ecology are grouped by Gadgil and Guha (1995) in to three categories; *omnivores* (non-local beneficiaries of the ecological resources, national or international), *ecological refugees* (displaced people who are displaced from their environment for varied reasons), and *ecosystem people* (those who depend on natural resources for their livelihoods). The western counterparts are termed as *biosphere people* (those who enjoy the produce of the entire globe) by Raymond Dasmann (1988). Different actors in the Madhupur sal forests can be tagged with these labels though this lineage is confusing while in a certain society different groups with different tastes and motivations may co-exist and/or overlap. For instance, a village school teacher or administrative clerk may be treated as a rural omnivore and at the same time he is an ecosystem person. But, for generalization or broad classification, the approach may work, even in the case of Madhupur forest.

Since the abolition of the Zamindari (feudal landlord) system in 1950, the forest lands were vested to the then East Bengal forest department and were later taken over by the forest department of Bangladesh after independence in 1971. From the very beginning, the government tried to hold and control lands through different legal mechanisms and plans. They sought support from international agencies and managed to get them to help execute government planning. According to the East Bengal State Acquisition and Tenancy Act (EBSTA) 1950, some of the lands in the forest were vested to the land revenue department, which are called Khas (untitled public) land and were distributed among the landless Bengali communities for living and cultivation in the late 1980s. This government initiative made the situation more complex, as the tribal communities alleged that ethnic cleansing is the real intention of this move. Some of the tribal groups (ecosystem people) extended their homestead and agricultural lands by clearing forests to indicate that the land is under their possession.

The forest and land revenue departments distributed a huge amount of forest and non-forest lands in the study area to other government and semi government entities, including the Bangladesh Air Force, the Bangladesh Agricultural Development Corporation, the Forest Industries Development Corporation, etc. These institutions have altered the land use of the area for their sole purposes. The local elites, politically powerful people, capital intensive merchants (local and urban) are important actors in the area as well; they exploit forest resources on a massive scale by influencing the local administration. Local communities are also responsible for deforestation but their contribution is insignificant compared with the deforestation caused by these other actors. Fairhead and Leach (1998) mentioned that there is a tendency of blaming the poor, ignorant, overpopulated local communities for all tree cover loss. The authors rather accused the forest authorities, colonial policy, and development initiatives for forest depletion and the poor rural communities are made out to be heroes of reforestation and afforestation through their homestead plantations, and community gardening (Fairhead and Leach 1996). The forest dwellers in Madhupur wish to protect the forests, as they can recognize its support and significance towards their livelihood. Non-governmental organizations are instigating action plans for locals to provide alternative sources of living which may be effective options to preserve and improve the quality of the forests. Local and national NGOs and charities are screening government plans, evaluating forest conditions and consulting local communities. They are also playing an important role in organising groups to establish their rights. Finally, the media and various writers are working in the forefront to disseminate messages about afforestation, deforestation, evaluation of agroforestry projects, corruption and conflicts to all corners of the society, which helps to put the different actors under some obligation for rectification.

7.6.2 Policies, Politics and Power in Deforestation and Forest Construction

It is a common consensus that the forest area in Madhupur is decreasing, though many efforts have been made to improve the situation. Multi-dimensional problems have been identified by different actors as to why the forest is being cleared out so rapidly. In general, each group blames others for the present crisis. There is a common tendency, for instance, for the forest dwellers to be blamed, but in my survey, although they confessed to cutting trees for their own household purposes, they were certain that the major theft is undertaken by the agents of local/urban elites and by the forest department itself, what Mitra (1979) (ci Gadgil *et* al. 1995) termed the unholy alliance responsible for environmental degradation. These omnivores capture resources by using the state apparatus (Gadgil *et* al. 1995) formed as an iron triangle (of civil beneficiaries, decision makers, administrators). It has also been reported in newspaper articles that forest officials are becoming taka millionaires by robbing forest resources. The shares in this crime reach up to the top level (see Daily Star, 10 April 2005) of the government machinery. Forest officials always maintain ties with local elites and national politicians, who either tacitly or actively support their activities at ground level. Blaikie (1980) described a similar pattern of ill-motivated activities of the elite class (politicians, bureaucrats, businessmen) that perpetuate problems of soil erosion in Nepal.

Politically motivated schemes are initiated and implemented in the name of forest protection, where personnel from different stakeholders find loopholes to receive personal benefits. The establishment of security installations, government training centres/farms in the centre of sal forest are major set-backs for the official government forest policy agenda because they have caused rapid forest clearing. In addition, the location of brick yards close to the forest has been overlooked by officials presumably receiving bribes, with the result that gangs are stealing timber to fuel the brick kilns. Clearings for this purpose alone have caused massive deforestation within a short time. Most of the respondents pointed to this as a much more important factor than cutting by forest people.

The establishment of rubber plantations by clearing out natural sal forest is another important cause of deforestation in the area, and this can be developed in many other vacant forest lands. Fifteen thousand acres of forest land in Madhupur Garh were proposed in the late 1970s for rubber plantations, but their introduction took some time beyond that. According to the Director of the Madhupur Rubber Plantation Project, the forest department gave 8,000 acres of forest land to the Forest Industries Development Corporation (FIDC) for a rubber plantation in 1986. However, some local foresters mentioned, even if the rubber plantation in Madhupur forests proves to be successful, such success is achieved at the expense of natural biodiversity that characterised the sal-dominated mixed forests.

Government or NGOs cannot create sufficient alternative employment opportunities for the local people to improve their social and economic life, so most of the forest dwellers still have to depend on forest resources for their sustenance. It can easily be argued that proper education and employment opportunities would deter the portion of the pressure upon the forest that comes from these people.

The social forestry programmes might open some possibilities for the protection of natural forests and improve the socio-economic condition of the local poor if these can be practised appositely. It is a common allegation of forest dwellers that local elites and politically powerful people are receiving forest plots for agroforestry or woodlot plantation, although some of them live in distant places. These distant beneficiaries lease out their plots to third party tenants, who use the land for maximum financial gain. These people, without having any emotional attachment to the forest, will not act in its favour as the locals can do – this statement by local people shows their resentment and frustration towards the current events.

7.6.3 Land Tenancy Disputes and Deforestation

Disputes over land tenancy in Madhupur forest area can be cited as a prime cause of deforestation. This complicated nature of land tenure has developed over several decades but it did not cause much harm in the past as competition over resources was not serious. Present government policies are sidestepping the original problem and adding further dimensions of complexity. It is, in this regard, necessary to discuss something about the historical land tenure system in Madhupur forest area and its evolutionary processes, where multifaceted uncertainties over land tenure and management are rooted and their impact on forest degradation.

The Madhupur forest was under Pukhuria *pargana* (now called thana) during the Mughal period (1576-1757) and also during the British period (1757-1947). The area was included in Mymensingh district in the nineteenth century. Sachse (1921) mentioned variations in the land tenurial arrangements in different parts of Mymensingh district and also in various parts of Pukuria pargana. Khaleque (1987) on the basis of historical documents suggested that zamindars collected land revenue from cultivators in this area from seventeenth century to 1950. This system of revenue collection, by appointing zamindars, who were an intermediary between the government and the cultivators, was introduced by the Mughals, who then ceded the right to collect the revenue of Bengal to the British East India Company in 1765. According to the key informants, the people living in the Madhupur sal forest area were allowed by the zamindars to live on and cultivate land within the forest in return for rent and labour payments for both arable land and their homesteads. Shifting cultivation was permitted under this arrangement subject to conditions intended to preserve the quality of the forest. The Garo were required to inform the zamindar's representatives, the nayab and sarder, about the location and amount of lands cleared for shifting cultivation. The maximum period of cultivation for food crops was set at three years, after which fields were reforested and the Garo community themselves had responsibility for this. My older key informants stated that the forest dwellers had fulfilled these conditions so that they could continue to live in and use the forest. Their rents were paid on time because they feared eviction otherwise. In return, the Garo community were granted a temporary right of usufruct, known as patta (table

13), by which the plot holder was allowed, upon payment of the usual rent, to cultivate the land and pass it on to his successors, but he was not allowed to sell it. The zamindar reserved the right to appropriate these plots, either in full or in part, for any public use without compensation to the plot holder (Jannuzi and Peach 1980). A more permanent form of land tenure developed over time as the Garo established wet rice fields. Following several years of wet rice cultivation with regular rent payments under the patta arrangement, a farmer could be granted the right of ownership, known as pattan, in return for which the zamindar was paid a royalty (Gopal 1949). Under pattan, the holders obtained the rights to sell their land or demand compensation if it were repossessed by the zamindar. Pattan was granted only for wet rice fields, not for plots under shifting cultivation. It is difficult to ascertain any precise timing from the statements of key informants on the evolution of these tenurial arrangements but they mentioned that the area was under Pukuria pargana and was an estate of a zamindar of Natore. After the abolition of the zamindari system in 1950, all the tree-covered higher lands in Madhupur forest area was handed over by the government to the forest department for scientific management through a gazette notification in 1951, while the right to control the low-lying wet rice fields was retained by the land revenue department. The forest was declared a reserved forest in 1955 and a part of this forest was demarcated as a National Park in 1962. After the forest department took over management, the local people (mainly the Garo community) were prohibited from using chala (high) lands within the forest for shifting cultivation. They were allowed to use the plots of low-lying lands for which they had valid documents. Both the high and the low lands have been occupied by the local people whether they have valid documents or not. The lands for which settlement was made with neither the forest department nor the cultivators belong to the revenue department; these are known as

Table 13: Historical Forest/Land Management Systems in Madhupur Forest.

Year/ Time	Regime	Management systems	Land ownership pattern/Key issues
1576-1757	Mughal	Zamindari system	Forest dwellers were allowed to settle and cultivate and given temporary land right called patta.
1757 (up to 1947)	British period		Pattan (right given to hold and sell land) introduced when Garo tribes started wet rice cultivation.
1860			Establishment of British Forest Dept. Forest conservancy began in Bengal in 1864.
1925			Forest Law introduced. All forests were taken over by British forest department.
1947-1950	Pakistan period		Pattan system continued.
1950		East Bengal State Acquisition and Tenancy Act, 1950. Forested chala lands given to forest dept in 1951. | Byde/cultivated and non-forest lands were vested to land revenue dept.	- Forest department started scientific management of forest lands. - Unsettled khas lands were distributed among landless Bengali communities. - Shifting cultivation abandoned and Tangua system (growing tree and crop together) introduced in the area.
1955		Madhupur forest was declared as reserved forest.	- Scientific forest management started. - Dispute started as Bengalis are introduced in the area.
1961		Madhupur sal forest was declared a National Park.	
1970		Land given for Rubber plantation and started on 4000 acres during 1986-90.	Uncertainty in the area and social movement against the rubber project.
1990	Bangladesh Period	Commercial plantation (woodlot, agro-forestry) started.	People participated in these projects but they are sceptical.
2000		Eco-Park project initiated.	Suspended due to community movement.

khas land (unsettled government land). A large amount of khas land was distributed among the landless Bengali community (the tribal community claimed that mainly criminals were introduced through this programme) in 1950s and in the 1980s. The hidden agenda here was to weaken the tribal dominance of the area. Not only in Bangladesh but the governments in other developing countries like Thailand, Philippines, Indonesia , Brazil (Lohmann 1991, Hecht and Cockburn 1989; Hall 1989) use the forests as a 'political safety valve' leading to forest change and resultant conflicts. In these cases forest are valued not for their timber, but rather as places to which surplus populations may be exported, thereby obviating the need for land reform (Bryant 1993). In Thailand, migrants flee 'an economy in which they have no secure place', but in Indonesia this process is formalized through an official 'transmigration programme' whereby six million poor Javanese and Balinese have been promised land if they settle in the outer forested islands. In the Philippines, a similar process occurs when low land farmers, whose economic opportunities have been marginalized, clear forest in upland areas. Peluso (1993) shows that the Dutch colonial government began the practice of excluding local people from access to forest land because of the high value of teak. This notion of forest use and displacing people from their ancestral lands by the third world governments/colonial rulers exemplifies the relations of political approaches of forest characterization (i.e. forestry, related policies) and the ultimate state of the woodlands.

The quinquennial settlement system of land revenue collection was introduced in 1772 by Warren Hastings of the British East India Company, which had established its authority as the government in 1771. Under this system, land was let out to the highest bidders without any regard to title (Sachse 1917; Bilia 1987; Chowdhury 1989), where the actual cultivators' rights were ignored. In 1790, this system was replaced with the Decennial settlement introduced by Lord Cornwallis. According to this system, settlements of lands were given back to the zamindars. The Decennial settlement was later made permanent by enacting the Permanent Settlement Regulations of 1793 (Islam 1979). The zamindars were now entitled by this regulation to exploit natural resources. Nevertheless, protecting the interests of the peasants was one of the aims of the Permanent Settlement Act. The zamindars were, therefore, instructed to give peasants written documents, known as patta (Chowdhury *et* al. 1989). Most of the zamindars exercised cruelty in the collection of revenue from the peasants, and this influenced the British to promulgate a right of occupancy act in 1859 to protect the raiyats (peasants) from mistreatment by the zamindars. The peasants were entitled to those lands which they held and cultivated continuously for a period of 12 years by this act (Gopal 1949; Jannuzi and Peach 1980). It was replaced by the Bengal Tenancy Act 1885, which stated that all of the persons holding lands under zamindars achieved the status of tenant-holders. These acts were not enough to control zamindar tyranny, however, and, as a result, the British rulers emasculated the zamindari system by abolishing the Permanent Settlement Regulation in 1940 (Chowdhury *et* al. 1989). The zamindari system was then finally brought to an end legally by the East Bengal State Acquisition and Tenancy Act (EBSTA) of 1950 and the process of acquiring zamindari estates by the government began that year. After this land reform, all land holders were brought into direct relationship with the government and all raiyats (subjects), according to this act, were to be called owners and they were entitled to have permanent, heritable and transferable rights to use their land in any way they liked (Siddiqui 1981).

As the tribal Garo people had probably been living in the area for centuries (Burling 1997), the acts automatically entitled them to hold the land they occupied. But as the local community did not preserve paper documents or sometimes no receipts were issued by the zamindars or by government officials, their claims to land have been ignored by the state agencies for decades. The forest dwellers believe that if they occupy certain amounts of land, government may consider their claim at some point. This perception has encouraged the locals to expand their homestead and agricultural lands by clearing forests in the hope of a future possibility of permanent possession and title. In contrast, the government is firm that the local people will not be given any permanent right of land if no legal document can be produced. This tug of war over land ownership is always ignored in government policy and success in forest conservation is thus never achieved.

7.6.4 Role of NGOs and Media on Deforestation

The primary objective of non governmental organisations is to bring about the changes which are crucially necessary for economic and social development of the people. In the Madhupur forest area, nine NGOs have been working (Gain 1994) for the improvement of the life of forest dwellers. Among them, prominent NGOs like PROSHIKA, SHED, SSS, BURO Tangail, World Vision of Bangladesh and World Tourist Mission are actively supporting people in afforestation activities (mainly by supporting social forestry), nursery and plantations, environmental awareness building, etc. Most of these NGOs are working for the participants under a contractual agreement with the forest department. But it was found during the survey that the role of the NGOs in protecting natural forest and forest related activities are not that encouraging. But some are having an impact, such as SHED which has brought Madhupur deforestation (through news media and different types of publications) issues in front of the public and national/international agencies, forcing the forest department to amend or halt some of their schemes. Also published materials like booklets, photo books, newspaper articles, posters and videos have made different bodies aware of the recent problems, and inspired this researcher to undertake a detailed study in the area. Under the guidance of some NGOs (mainly by SHED), a group of journalists has developed who are focusing mainly on nature of the deforestation processes, identifying people active in deforestation and afforestation issues, policy problems and corruptions, biodiversity loss, and so on. Although the available materials from these sources are not academically rich, as Robbins (2004) has mentioned, these are nevertheless important from the political ecology point of view to apprehend the contextual background of the problem. NGO activists have played an active role in the area in making people aware of their customary rights to land and forest resources and about their identities, leading them to formulate groups for a common voice. In addition, local Christian charities (like the Jalchachtra church Mission, Caritas) are educating the local Garo communities and supporting them in securing their long term demand for land rights. The NGOs organize workshops and conferences at local and national level on issues related to the benefits of the forest and of its people. National and local experts through these events call for action to rectify government policies and actions.

7.7. Evaluation of Political Ecological Thesis

7.7.1 Degradation and Marginalization

In this thesis political ecology offers an explanation of why and how environmental systems change. Disputes over existing land tenure issues; faulty policies (and conflicts between policies); imposed development projects (top-down) without consultation with local people; and the avoidance of root problems as the origins of land degradation in Madhupur sal forest have all been examined under this theoretical framework. Making room for different projects like commercial plantation, capital accumulation by tourism, and the establishment of security installations are the processes responsible for landscape clearance in the study area. On the other hand local people are attempting to hold the maximum amount of forest land under their personal control in the future hope of legitimate ownership. The locals confessed to this latter strategy to me and mentioned that they are anyway bound to fell trees to offset their own needs. This activity and perception of local people has brought forest resources to the point of over-exploitation. Rigg (1992) similarly shows how local farmers in Thailand have cleared out forest resources to extend their cassava, maize and sugar cane cultivation area. He argued that population growth and commercial development have led to the rapid expansion of cash cropping and have had a strong influence on forest depletion, though Gadgil *et* al. (1995), and Yapa (2004) oppose this theory. Rather they mention that structural failures are more responsible for such kinds of human deeds and those scarcities are socially constructed. Whatever is the cause, population pressure or structural factors, the depletion finally creates natural resources scarcities and pushes people further towards economic marginalization, in a downward spiral. The failure of the state authorities to maintain equity in resource allocation or appropriation exacerbates mistrust and antagonism in the community. Furthermore, the control of natural resources in the name of conservation by state authorities and outside firms has encroached on customary property rights. However, it can be argued that the level of forest degradation and its associated complexities in the study area has already passed the threshold, and now has such a momentum that it will be difficult to reverse within the current policies.

7.7.2 Environmental Conflict

The survey exposed the frustration of local people when they found that the state authorities give favours to the politically powerful, businessmen and local elites. This breakdown of justice in resource allocation in Madhupur forest has put forest dwellers in a resource-tight condition and generates further tensions and competition between ethnic groups, classes and genders. The Bengalis are trying to exclude tribal groups from natural resource allocation by persuasion of the authorities. The government is also introducing new Bengali settlers in the area by distributing khas lands. Sometimes tribal minorities or defiant groups hardly represent a homogeneous cluster with shared interests. There are many who have embraced the 'modern' world and its lifestyles with alacrity; others have sought to protect 'tradition' (Hirsch 1990). Thus, it is evident that there are conflicts among tribal groups over resource control and use. The state authorities sometimes get benefits from these tribal splits by offering extra advantages to a certain group to favour of government actions and undermine the morale of their social movements.

Thus ecological problems have become socialized, with effects upon communal morale, mutual trust, social organizations and institutions. These breakdowns are taking place as the proposed programmes/resolutions of state/international bodies are mainly based on imaginaries of the planners who are not part of the local community. For instance, the same type of social forestry is applied in most of the South and Southeast Asian countries (Colchester 1993) irrespective of spatial differences, suitability and acceptance of local people, with the Asian Development Bank as the mastermind behind this construction. This seclusion of the forest, limits the planners in apprehending local customs, needs and choices when formulating their policies. This is certainly true in the case of ongoing Madhupur forest management measures, where planners have failed to assess disputes over land tenure and failed to consider social factors (like social structure, ethnicity, gender) as differential environmental access and responsibility.

7.7.3 Environmental Conservation and Control

The Eco Park Project

One of the major crude examples of the control of natural resources is a proposed eco-park project in the area. The forest department of Bangladesh tends to see its natural resources as revenue-earning capital. Sattar (1997), the Conservator of Forest, in his term "Management of Park as an Industry" outlined the necessity and mechanism of making revenue from local and foreign sources using national forest resources. In the first step of forest control in the area, the Bangladesh Forest Department created the Madhupur National Park in 1962 on an area comprising 20,838 acres (8433 hectares) of land (The Independent 13th April 2001; Daily Janakantha 13th June 2003). Initially the project was proposed with the aim to save forests from people's (legal/illegal?) occupation and use (like grazing and fuel wood collection). The forest Department poured a big amount of local and foreign currency in different terms (19965/66 to 1969-70 and 1974/75 to 1979/80 and recently in 2000; see government internal article on the Madhupur National Park Development Plan, 2nd July 2000, Ministry of Environment and Forest) to achieve the objectives of the project. They classified the Madhupur forests into two major zones as core and buffer for the purpose. The forest Department, in the name of park development, converted forest land use into recreational land use (establishing picnic facilities, rest houses, bridges and road networks etc.). At present an average of 50,000 people visit the Madhupur National Park every year for winter picnics (The Independent 13th April 2001). Encouraged with the success of revenue income from this event, the Forest Department decided to develop more facilities in the core zone (in the name of eco-tourism). At this stage, they erected concrete walls around the core zone and created artificial lakes, rest houses and more attractive picnic spots to attract foreign tourists with foreign currencies, but it was at the cost of local livelihoods. With financial support from Asian Development Bank (of taka 100 million), construction of a 5 kilometre stretch of wall has already been completed (The Daily Star 4th May 2003) and the remaining construction process is proceeding at this moment. I and another Japanese researcher , during my field visit, witnessed some anarchic moments in the deep forest, where local contractors (politically backed as well) were erecting walls in the presence of local forest officers and three wagons of armed forces (I avoided taking photographs for obvious reasons). A few hundreds local (men, women and children) formed a protest march near by. On the other hand, I also witnessed some locals (tribal members) supporting the government officers (in their presence) to complete their tasks. The Government dealt in an underhand way with latter group in order to win their cooperation. Each time any local people enter the area through the boundary wall, they have to pay taka 6 to 8 as a toll for taking a van load of fruits or vegetables. This government plan (which started implementation in 2002) to erect a concrete wall to cordon off three thousand acres forest lands for eco-tourism has ignited anger and violence among the 25,000 sal forest dwellers (The Daily Star 4th May 2003; Prothom Alo 5th June 2003). Their fear is that this eco-park project is an excuse to evict them from the area and they consider it a life and death issue because they know that, without the support of forest resources and free movement in the area, it will be impossible for them to live. The government do not see that the forest dwellers, their life and interaction with nature as an interesting element of the tourist attraction, but rather they are viewed as a risk to the plan. This separation of environment from society has fuelled existing problems in the area and caused interruptions and eventually forced the authorities temporarily to suspend the project when one tribal man was shot by a forest guard in January 2004. This project, in addition to other existing schemes, is in every way imposed by the political authorities as they purposefully tend to see 'wilderness' landscapes as devoid of people, farms and cattle

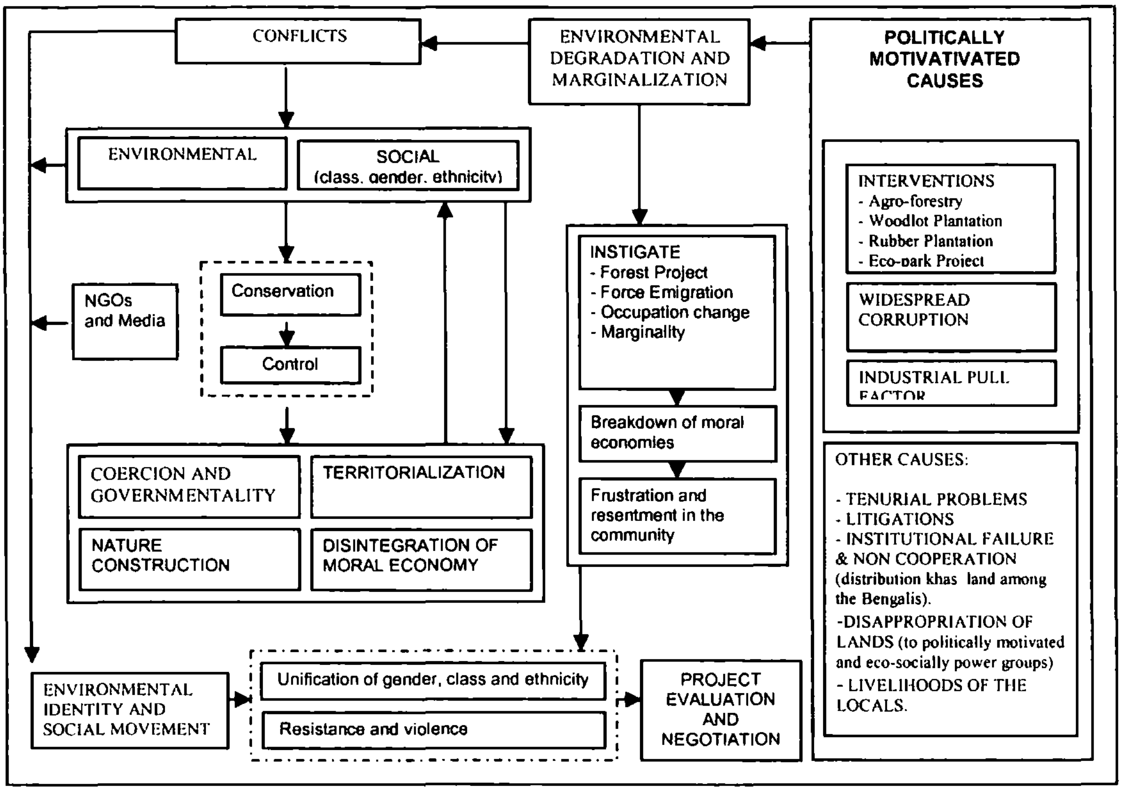


Figure 9: Causes, Control and Conflict Cycle of Deforestation in Madhupur Sal Forest.

and their commodification of landscapes (by tourist consumption and commercial tree plantation) has contributed to the breakdown of the social and ecological sustainability of the Madhupur forest. Cordoning off wilderness in the area by splitting up forest lands into small parcels for project implementation demonstrates the coercive attitude of governmentality (figure 9), where communal norms and practices are replaced by state rules. This disintegration of the moral economy through the control of natural resources in the name of conservation by state interventions is pushing people and nature into crisis conditions. Bryant (1993) shows how patterns of natural resource control of the state (i.e fire-protection programme, forcing locals to plant teak known as *taungya*, banning cutch production) ignited community resistance in colonial Burma. Figure 6 illustrates the cyclic forms/actions of factors that influence and give shape to the Madhupur sal forest.

7.7.4 Environmental Identity and Social Movement

The forest department and local people have been confronting each other ever since the take over of the forest by the forest department in 1951. Complicated land tenure systems, a lot of litigation, inefficiency and corruption of the forest officials, improper policy planning, a lack of consultation in designing and implementing forestry projects, and favouring of local elites in the distribution of forest lands for different schemes, have all caused antagonism among the tribes and the Bengali communities against the government agencies, while the forest department is blaming locals for illegally encroaching on forest lands (table 14).

Table 14: Enchroached Forest Land in Tangail District (in hectares).

Thana	Total Forest Land	Enchroached Forest Land	Number of Encroacher Households	Recovered for Woodlot and Agroforestry
Madhupur	18,447	8,590	8,201	1,811
Ghatail	8,848	5,471	4,649	2,218
Shakhipur	19,118	8,333	10,259	3,925
Kalihati	267	137	112	-
Mirzapur	3,067	1,828	1,103	483
Total	49,747	24,359	24,324	8,437

Source: Forest Department 1999.

The forest department has filed a large number of judicial cases against local people for taking over land (the forest department calls them encroachers), which the locals allege are false. The amount of encroached land is about 24,359 hectares in Tangail forest division under 2,763 hanging litigations in court, while the total number of encroacher households of those lands is 24,332 (Forest Department 1999; Hossen 1997; Daily Ittefaq 28th October 2000). The forest department has also filed a huge number of cases against locals for tree theft. The local forest officials/guards are authorized to file a case without any witness (under Forest Amendment Act 1990/26A) and this provision makes them capricious, as was evident when a five-year child was charged with tree felling (Daily Sangbad, 22nd August 2002). The respondents claimed that the forest department has filed many cases just to prove that they are active in forest protection at field level and to divert attention away from their own corruption (see stories in the *Daily Ittefaq* 15th February 1998; *Dhaka Courier* 26th June 1992; and the *Bangladesh Observer* 11th June 2001). However, these multifaceted problems and war of claim and counter-claim has resulted in non cooperation with the forest department, community demonstrations, and the submission of community petitions to the ministry claiming forest lands. For instance, a community appeal placed before the government in 1996 by Madhupur forest dwellers claimed 37,163 acres of forest land upon the argument of customary rights and the claim that they and their forbears have been living in the area for generations. They submitted age-old documents in support of their claim. Out of 2391 different petitions, the government has agreed to give back land in 702 cases (Forest Department 1997). This remarkable community movement has united local people of response/movement at the grass roots is along the line of what Scott (1985) called everyday forms of peasant resistance and it has put government machineries under some obligations so that they cannot do whatever they wish. In other words, in the absence of these voices the remaining forest might have vanished long before.

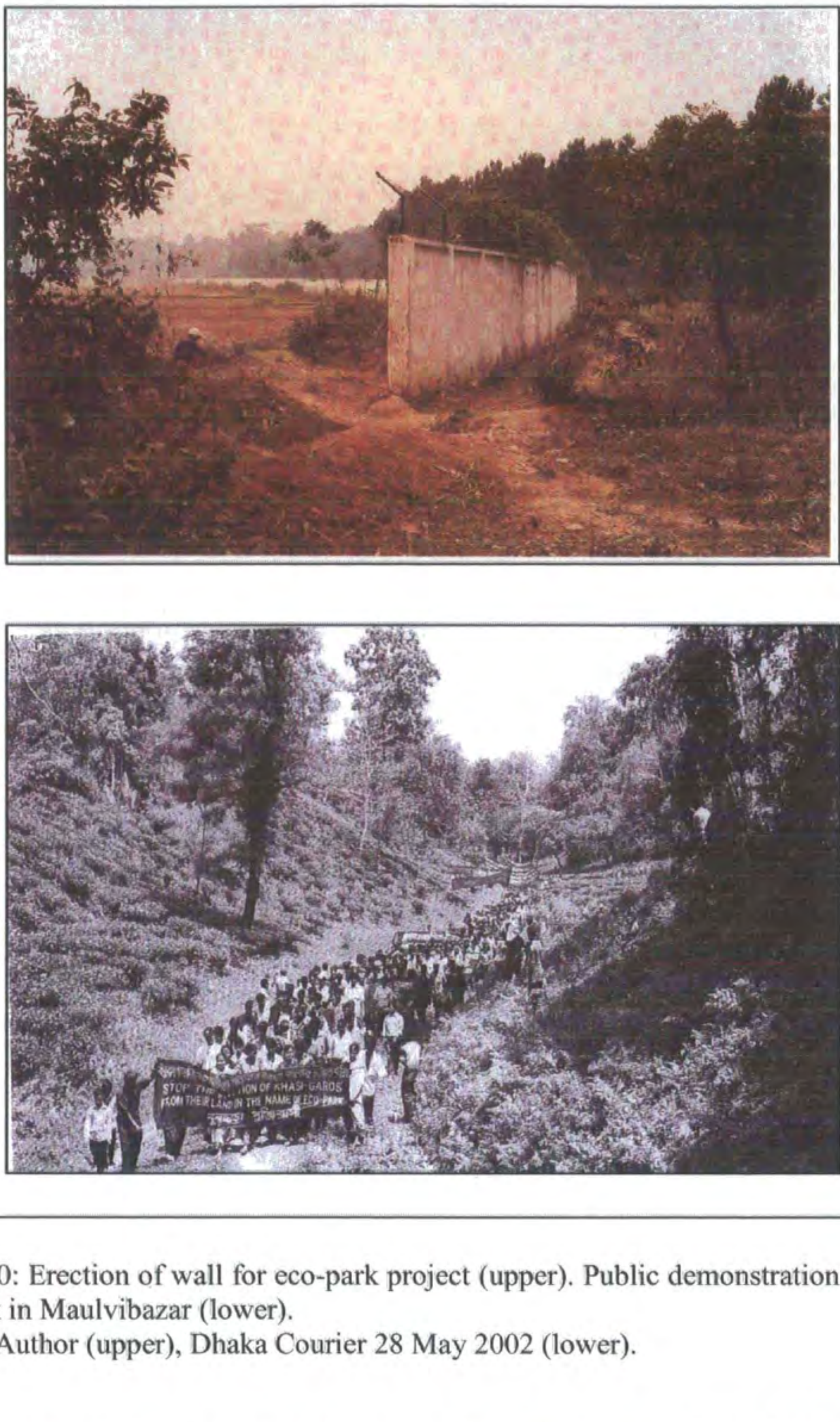


Figure 10: Erection of wall for eco-park project (upper). Public demonstration against eoo-park in Maulvibazar (lower).
Source: Author (upper), Dhaka Courier 28 May 2002 (lower).

different races, classes and genders and these movements have been backed (intellectually and technically) by different NGOs and Christian charity missions. The

However, it can be argued on the basis of surveys, discussions with local institutions/NGOs, and other key personnel, that dispute over land tenancy is the main cause of deforestation in the Madhupur sal forest. Successive governments of East Pakistan and Bangladesh have ignored the issue and instead taken control over the land by issuing different laws and policies and implemented projects that have been a means of expelling a large community from the forest without compensation. There is now fear and suspicion among local people about any social forestry or other programmes.

7.8 Conclusion

Gadgil and Guha (1995) in their book 'Ecology and Equity' propose to investigate the chronic shortage of natural resources from a worm's-eye view, while bird's-eye view sometimes fails to reveal the drivers of environmental change. This chapter has sought to reveal the factors underlying deforestation in Madhupur sal forests, using the worm's eye view and a bird's eye view (remote sensing techniques) has provided strong evidence of massive deforestation. This was possible through an analysis of social dynamics, vested interests and activities of different actors/stakeholders, the historical legacy of land tenurial disputes, the making of forests based on state power, and political and economic views of natural resource management. Ignorance of these issues in policy planning in the last several decades has left the forest resources in a delicate state. Sometimes even the foresters have lost control of forestry decisions to politicians; decisions are made above their heads often with minimal or no consultation (Whitmore 1993). They did not move outside their narrow technical field to argue the case for forests in the national economy and decisions are made by economists, bankers and planners with inadequate knowledge and false perceptions about forests (Palmer 1989). These types of imposed plans and directions, what Blakie and Brookfield (1987) termed as top-down or structural determinism, handicap sincere forest officials who wish to act in favour of forest protection. However, the political ecological approach, as used to describe the deforestation process and to understand the complex relations between nature and society (Guha 1989, Peluso 1992, Bryant 1993, Rocheleau 2001, Peet 2004, Watts 2000) in this chapter, has helped in apprehending these factors and in future could be used to formulate propositions that can address the problem and bring the forest back from the point of no return. But there is still uncertainty about the ideal concept/model that may help the planners and practitioners to save the environment and at the same time open the resources for rural livelihood sustenance. For instance, environmental scholars are highly sceptical of the merits of the most recent concept of sustainable development (Bryant and Bailey 2000) approach of natural resource management, that is already in operation in many developing countries including Bangladesh by DFID (http://www.livelihoods.org/), UNDP and CARE. On the other hand they (mainly political ecologists) have yet to develop an alternative to the mainstream concept of sustainable development. Hence, the proposal of Gadgil *et* al.(1995), for *conservative liberal socialism* stands on a synthesis of positive aspects of philosophical bases rooted in different thoughts or the hypothesis of environmental pragmatism may add some light in tackling third world environmental/ecological problems. It is necessary to open our stance (to resolve inter and intra conflicts between science versus social science, rich versus poor, modern technology versus indigenous technical knowledge, planners versus practitioners, etc.) so that we can include lessons from tools, concepts, events for developing more practical and efficient methods. For example, if we do not learn from the perilous decline of fugitive natural resources (i.e. fisheries) in the

North Sea (Kaiser 1998) or Cumana region of Venezuela (Humboldt 1852, ci Robbins 2004) due to imprudent human activities, it will obviously be very difficult to protect any easily detectable non fugitive resources like forests. The honest wish of humankind to protect the natural resources is more important than technology or approach because we have seen the decline in both the cases when using modern gear (in the North Sea case) and with relatively less technological support (in the Venezuela case) to destroy resources. Hence, our positive wish may help to find appropriate tools/concepts, ways of reciprocal justice and cooperation, prioritize needs-orientation and self reliance, as Nerfin (1987) calls for 'another development', to save the remaining dwindling natural resources and to regenerate new colonies.

Chapter 8

Integrating Science and Social Science for Appropriate Forest Management in Madhupur Sal Forest

8.1. Introduction

Forests in the tropics are depleting rapidly (Foody *et* al. 2001) at a time when forest protection issues (in the name of sustainable yield forestry, sustainable forestry or sustainable forest management) have become a global concern in both international and national policy dialogues. Attempts have been made to establish a global regulatory framework for forest management through agreements, principles and criteria but there is strong evidence that net deforestation continues unabated (Johnson 2005). This failure to keep the forests unharmed indicates a gap between ambitious commitments to policy by governments for natural resource management and the actions required to be taken to address the fragile state of the resources in the field. The problem is particularly serious in tropical forests, where there is uncertainty about the statistics on forest cover attributes and dynamics (Foody *et* al. 2001, Achard 2002). Foody *et* al. (2001) have further mentioned that most research in the tropical forest environment is focused on major land cover conversions and the subtler modifications that ultimately lead to serious degradation are ignored. Uncertainties are also caused by the demographic, economic, social and political attributes that are fused with forest components (Geist 2001). The problems associated with tropical forests are traditionally seen as the impact of immediate factors (like population pressure), and the root causes mainly driven by political policies/decisions, are generally written off (Bryant and Bailey 1987). Said (1978) mentioned that the way problems are presented (i.e the narratives and rhetoric) are contingent upon the socio-political, economic, cultural context. This means that there are a number of different ways of treating the same environmental/ecological problem and so Blaikie (1985) has argued that problem identification and prescribed solutions are different according to differences in ideological, political and methodological strands. Therefore, we need a new and practical approach where the (forest) problems can be assessed within the interweaving fabric of socio-political background in the national and/or international context (Zimmerer 2006), because sometimes it is hard to infer whether the problem is ecological, political or economic. Political ecologists for the last two decades have been trying to respond to these issues by assessing the complex relations of nature and society. It has been shown in previous chapters that uncertainty around forest issues in the Bangladesh context is deeply connected with social factors. Scientific and social science approaches, therefore, have been employed in this thesis in an attempt to focus on those physical-social relations that impact upon the condition of the forest. Chapters three and four focused on assessing the state of forest resources using remote sensing techniques, and, on the other hand, chapter five and six discussed the social components (based on political ecology) of the problem. This chapter attempts to make a link between science and social science methodologies to better understand the problem.

8.2. A Recapitulation of the Problem

Deciduous sal forests located in the central parts of Bangladesh are an example of uncertainties (mentioned above) about its resources that are heavily impacted by the socio-political processes/factors. The Government of Bangladesh has been adopting policies and implementing actions without proper knowledge of the local issues concerning forest resources. Exaggeration and misrepresentation of the resources is the norm, not the exception, in forest statistical reports (Gani *et* al. 1990a, 1990b, MoEF 1999, Forest Department 1999). This lack of a knowledge consensus tends to favour groups in society who get illicit benefits from forest assets.

Ignoring pertinent scale issues is a major dimension of uncertainty in the area. Uncertainty arises around the questions of what level of forests units (stand level, landscape level or ecosystem level), or forest boundaries (legal, political or territorial) to consider for resource management. Uncertainty also persists in terms of forest structure and health and their cartographic representation. These ambiguities arise because of the inadequacy of the statistical models (Blaikie 1985) in practice to give empirical evidences and proof of the problem. My research, in that regard, has focused at local level in order to monitor the pattern of forest cover change, and to assess the stand quality issues using established methods of satellite remote sensing. The research also covers problems associated with social variables and policy concerns that have impacted on the resources. I have generated new sets of information and compared them with existing sets and, as a result, argued the need for a bottom-up approach for forest protection and management. It is hoped that the aggregation of locally based evidence may help to step up regional and national awareness of the problem. It is then a matter for policy makers, bureaucrats and politicians as to whether they protect, modify or destroy natural resources, because they are still in the driving seat.

8.3. Link between Pattern and Process

There is a close link between the pattern of forest data representation and the process of forest change. In the same line of argument it can be said that the process of decisions and activities in the socio-political context are intermingled with the pattern of landscape, which has already been modified by them. Forests are shaped and depleted, and species diversity is changed as a result of human choice and actions. For instance, Gani *et* al. (1990a) mentioned in an official publication of Forest Department that "choice of species should be made on the basis of need and market for the surplus produce". These choices have been limited to the fast growing Acacia varieties recommended and financed by international aid and financial institutions - the Asian Development Bank in the case of the Madhupur Forest. This has ignited controversies in the area (see chapter five and six for more discussion). A large amount of money has been poured into the woodland projects in Madhupur in the name of amelioration of the forest condition. However, the nature of the development appears to have resulted in further depletion of the sal forest resources. For example, fourteen projects, as mentioned before, under various names have so far been implemented in the area but their final results have been further forest degradation (Bhuian 1994). The failures of these woodland projects are never contested or reviewed in order to learn lessons from the flaws, and the root causes of the crises have never been explored. Rather the decision-making bodies have simply moved on to the next development plans for the area. This cycle continues because the people in general, the civil society groups, and even sometimes the top policy planners are not aware of the actual condition of the forest.

There is a tendency by the public institutions to obscure forest information (Farooque 1997, Gain 1994). For instance, Bangladesh Forest Department in 1990 produced a major report, entitled *The rehabilitation and land use planning of sal forests*, with the technical and financial assistance of the FAO and UNDP. The three volume report mainly outlined social and agro forestry plans, which have no link to the title or the aim of the report (i.e natural sal forest rehabilitation). A remote sensing team (from Asian Institute of Technology, Thailand) worked for the study team to provide them with forest information, using Landsat TM data of 1989, but the statistics are not properly reflected in report, nor was any map included. A hand drawn generalized map of the forest cover was inserted when a remote sensing support team was available.

This pattern and rhetoric of problem representation indicates a tendency to engineer processes aimed to give illicit benefits to certain sections of the community in the name of forest rehabilitation or sustainability of the forest. Such patterns and processes also have a direct link with the political realm of society. Politicians authorize the actions and proposals proposed by the bureaucrats and policy makers that sometimes do not go in favour of the forests, especially in the case of Madhupur forest. Sometimes politicians directly seize forest lands illegally (*The Daily Star*, 10 May 2005).

Bangladesh is not only the country having this type of crisis. Many third world countries, like Indonesia (Foody *et* al. 2001), Philippines (Apan 1997), Brazil (Houghton *et* al. 2001), endure something similar. The commonly mentioned causes of deforestation (discussed later) are no longer the primary drivers. Rather, political decisions and the vested interests of powerful groups are responsible for shaping forest resources.

Responding to these issues, there is a growing body of literature under the theoretical banner of political ecology (Bryant and Bailey 1987, Zimmerer 2006, Zimmerer and Basset 2003, Robbins 2004, Peet and Watts 1990, 2000, Stott and Sullivan 2000), which argues that addressing the root causes could help to save remaining woodland resources. Evidences/information produced in my own attempt using remote sensing techniques is a proof of the type of pattern and processes of forest change along the lines of political ecological arguments. Remote sensing techniques have shown that forest resources can be quantified accurately (McRoberts 2005, Katila and Tomppo 2001, Donoghue 2004) in terms of their quality, health and structure. In addition, temporal change analysis and mapping that can be used to monitor the pattern and processes of change. The availability of such information on the true representation of forest resources may bring some transparency in actions of the various stakeholders as well.

8.3.1. Addressing the Information Gap

It is repeatedly mentioned both in government and non government reports that the information about forest resources in Bangladesh is uncertain (Farooque 1997, USAID 1990, Gani *et* al. 1990a, Forest Management Plan 1993). Statistics are often exaggerated, presented in a generalized fashion and in broad categories. It is always claimed that the lack of resources and technical know-how are the barriers to producing up-to-date information. Current government statistics suggest that the total amount of deciduous forests in country is 120,000 hectares (BBS 1998, MoEF 1997), 86 percent of which is in the central region (figure 1 in chapter 3, page 42) and the remaining 14 percent in the north western parts of Bangladesh (Gani *et* al. 1990a, 1990b). The resources in the central parts are distributed in three districts (i.e Dhaka, Gazipur and Tangail). The main concentration is situated in Madhupur thana of Tangail District (the study area for this research). Government statistics show that the total forest land of Madhupur thana is 18,447 hectares, where 8,590 hectares of land are encroached by the local inhabitants (MoEF 1997). These statistics indicate that 9857 hectares is covered by forests in the thana, what is completely different from my study results, see chapter 3. Detailed cartographic presentation of the resources has never been done other than producing some very generalized maps of the resources. Moreover, quality issues in terms of forest structure are rarely included in the published statistics. It is unclear whether the forest department is unwilling to produce actual information about resources or whether they know but are unwilling to publish data in the public domain. It is reasonable to raise this question because for unknown reasons the Forest Department maintains a remote sensing laboratory in their head office for resource assessment and mapping but the unit is left inactive. During the field visit for this research in late 2003, the author failed to interview any senior officials on the matters of deforestation, forest management, or remote sensing activity. Even, the staffs in the remote sensing laboratory were instructed not to talk the author without prior approval of the Forest Department. The space research organization of Bangladesh (SPARRSO) is also available to the forest department for technical support but they are not called upon to clear up the uncertainty about forest resources.

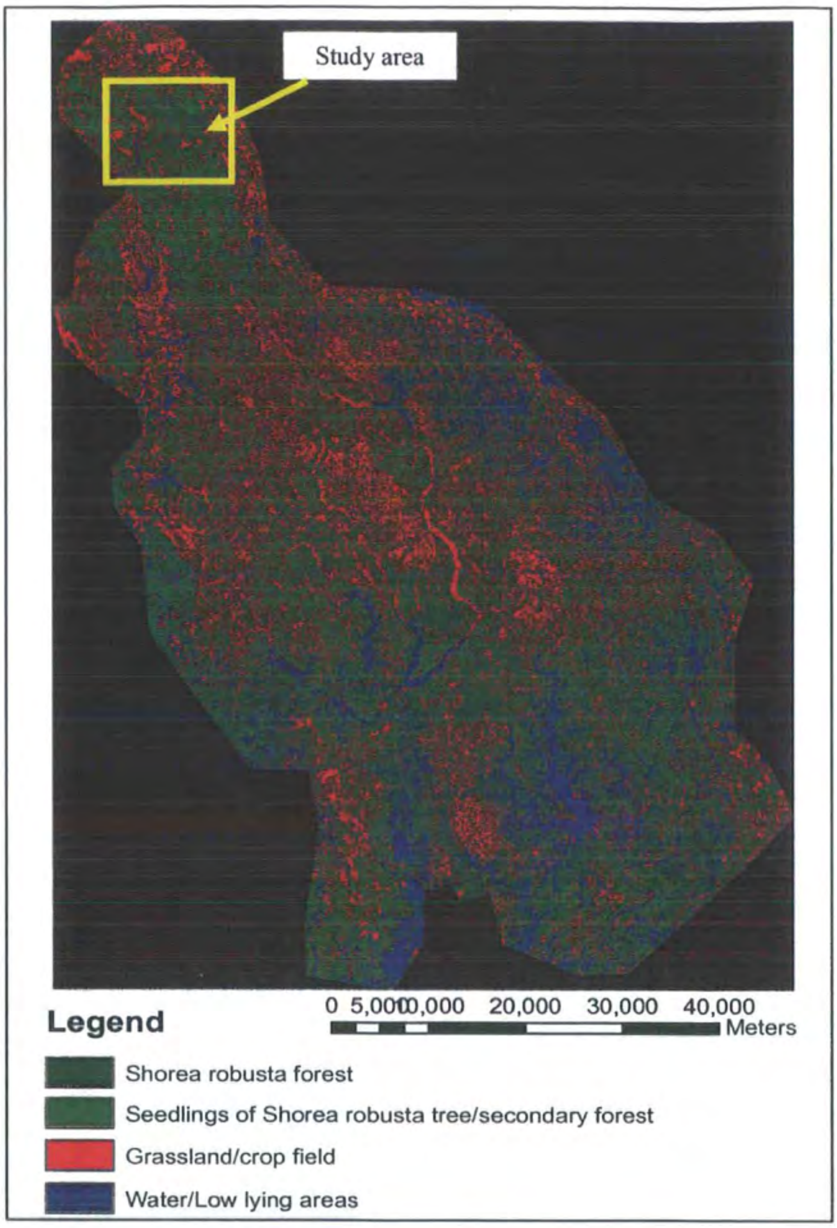


Figure 1: Unsupervised classification of the whole tract area showing forests (using Landsat ETM+ 2003).

The results of my remote sensing analysis challenge the forest statistics published in government reports. I have found that the condition of the resources in 1962 was good (3800 hectares forest were found in Corona satellite image, see figure 2 in chapter 3, page 49). Even the fringe areas which are completely deforested now were covered with forests (Figure 2) at that time. Landsat ETM+ data suggests that the area has reduced to about hectares 2025, including 1270 hectares closed canopy and 755 hectares open canopy forest in 2003. But the high resolution Quickbird data (from 2003) indicates that only about 594 hectares of land are really covered with closed canopy forests (figure 12, chapter 3, page 79). This difference between Quickbird and Landsat ETM+ data emerged probably from the spatial resolution issues of the satellite data (for details, please see discussion part in chapter 3). Chapter three discussed in detail the spatial and temporal change of forests. Forest quality issues are appraised in chapter four, which shows that the structural pattern of the forests in terms of biophysical variables which can be assessed using satellite remote sensing techniques - although it is important to note that some authors (Nelson *et* al. 2000) are sceptical of the merits of remote sensing application in tropical forests because of its rich biodiversity and complex canopy structure. Prediction and mapping of forest variables based on statistical models also demonstrate the capability of remote sensing. The regression coefficients (R^2) (see figure 14, chapter 4, page 130) of predicted results compared to field data indicate that mapping and quantification of forest resources can be improved by adopting this state-of-the-art technique.

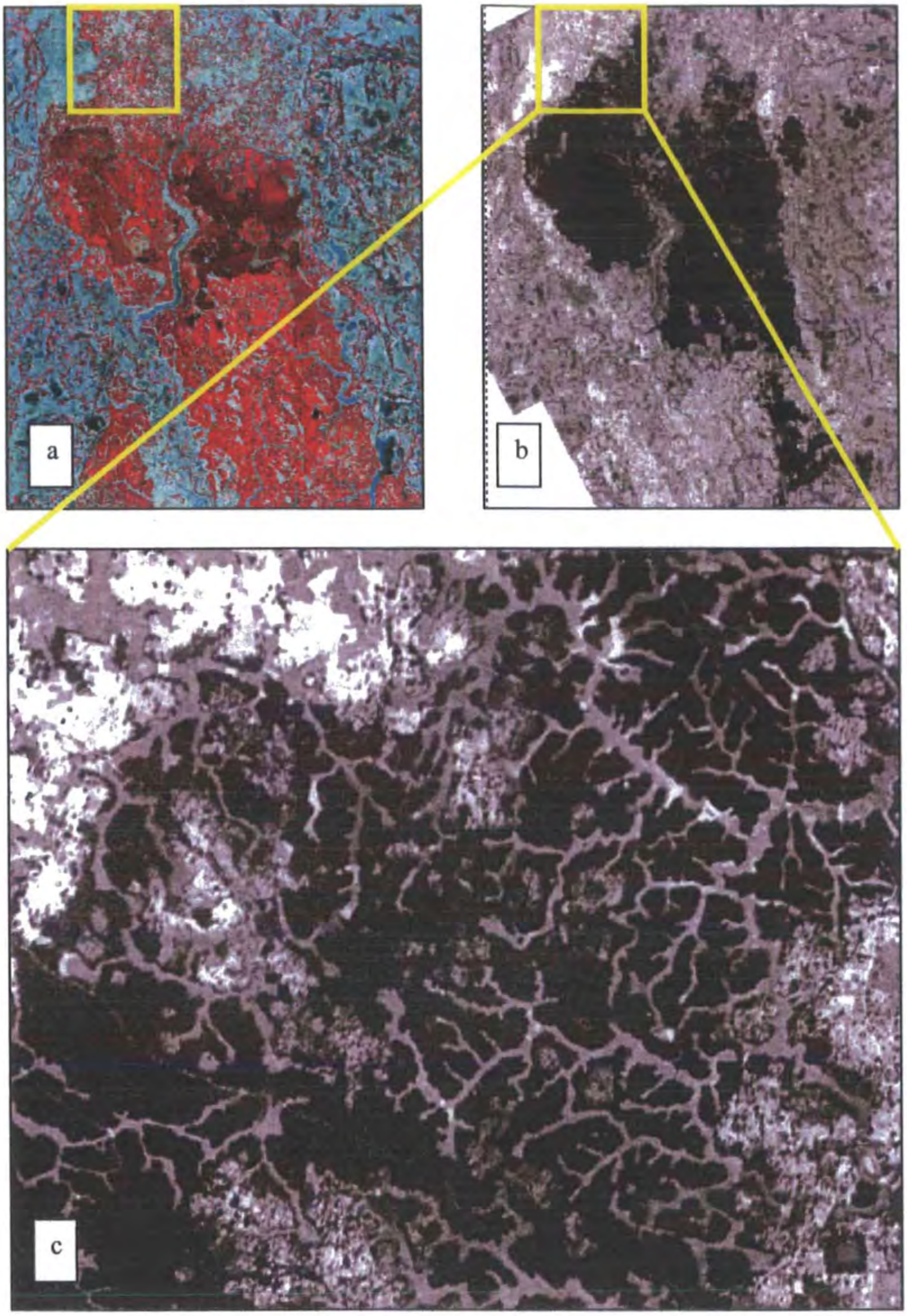


Figure 2: a. Landsat ETM+ (January 2003); b. Corona satellite image (November 1962); c. forest distribution along the creeks in zoomed in Corona image.

An information gap and poor representation of forest data is also evidenced at the very local level of forest management. The local forest office in Madhupur thana uses a hand sketch map (figure 3) to assess forest land use and to monitor progress. This local forest office marked their success by indicating those areas on the maps that has already been converted to agro-forestry schemes (red colour in the sketch map). They consider forest land conversion into agro-forestry schemes or bringing more area under social forestry/agro-forestry as an achievement. Their office room is also decorated with the statistics of revenue-earning from the agro-forest projects, graphs of the distribution of plots to poor families, and with statistics on the number of police arrests and court cases against local people. There is a clear departure here from notions of the professional forester who manages, protects and monitors forest resources and there is a negligence and lack of commitment in taking care of the natural forest resources. The local level junior forest officers informed me (figure 4, left) that they are mainly busy in the judicial court to deal with cases and find limited time to take care of the forests. A local church leader, father Homrich, who has been living in area for about forty years, told me (figure 4, right) about the dynamics of deforestation in the area and he clearly indicated that government policy and lack of transparency of forest department (i.e. corruption of forest officials) are the main causes of forest clearance, though the local villagers are usually blamed. He was one of the key informants who helped with the recognition of forest/non-forest features on the Corona satellite image of 1962. In a similar study, Shepard (2004) received help from local tribes in interpreting remote sensing classification schemes, but in my research the ordinary inhabitants were bewildered. This was partly because they

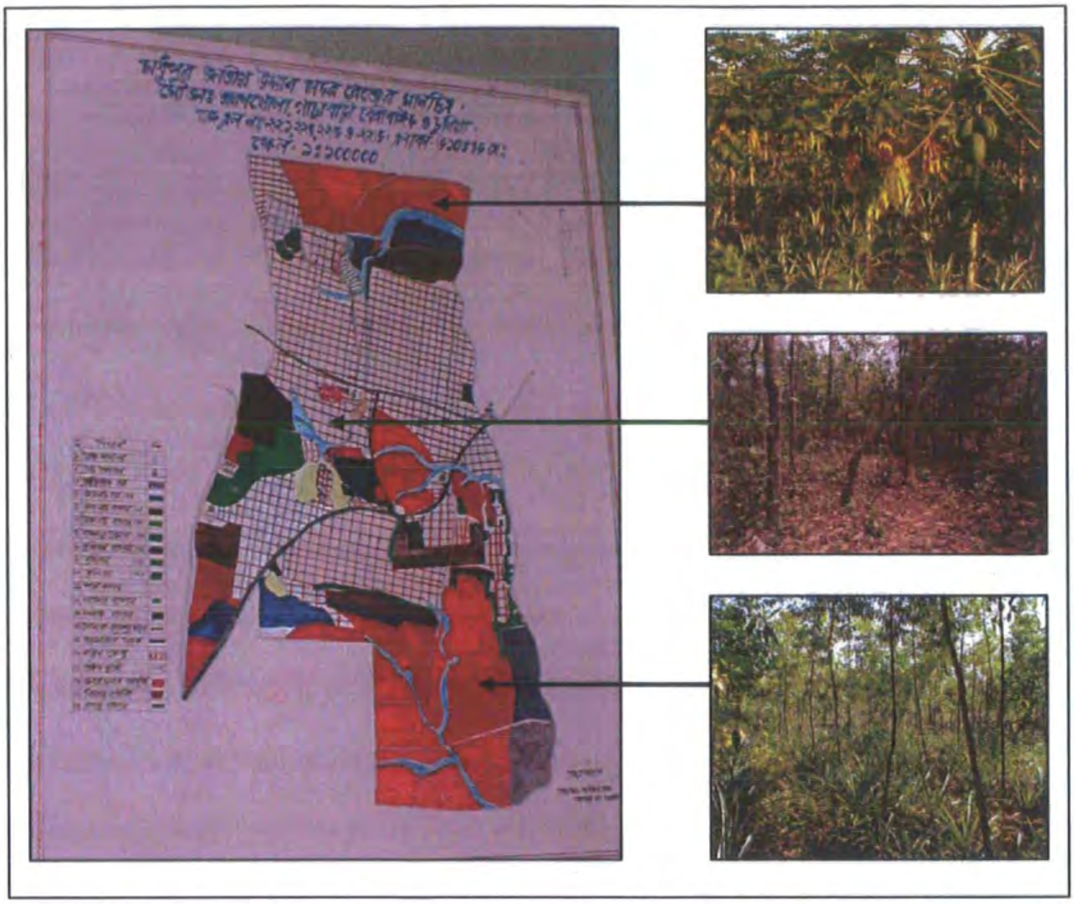


Figure 3: The map (hand drawn sketch) used by Rasulpur forest office (government forest office located in the study area). The photographs showing the types of land use (agro-forestry in the upper two and forest land use in the middle).

Figure 4: A local forester describes the way they manage forest resources in the area (left), and Father Homrich, who has been living in the area for the last forty years helped me to interpret features on remote sensing images and gave a fruitful account of the nature and causes of deforestation (right).

were seeing a forest distribution in map form for the first time in their lives. Once acquainted with the maps, they were able to give me important information about forest quality and change (spatial and temporal).

8.3.2. Reviewing the Causes of forest Change

The Government consider the local people as the prime factor in deforestation. They are blamed for illegal occupancy of forest lands, removal of trees, illegal grazing and fuel wood collection (MoEF 1999). These factors are responsible for deforestation to a certain extent without doubt but are not the prime ones. The prime causes revealed in this research are (as discussed in chapter 6),

(i) not addressing land **tenancy disputes** in the area and therefore perpetuating antagonistic relationships;

(ii) improper policy implementation, flawed by a **lack of accurate information** on forest quality and quantity;

(iii) active and passive **corruption** of different groups (i.e. forest officials, guards, and some groups in the local community);

(iv) **a neo-colonial attitude towards forest management** (including a revenue-earning attitude at any cost);

(v) **lack of auditing/evaluation/monitoring** of forest resources, development projects and the activities of personnel.

The forest department have created a hostile relationship with local inhabitants over the issue of land tenancy disputes (please see section 6.3 in chapter 6, page 207). The Forest Department calls the inhabitants encroachers; on the other hand local people call the forest department illegal occupiers. Remote sensing results, in this regard, suggest that the people have been living in the area long before the establishment in 1972 of the Bangladesh Forest Department and so have a certain legitimacy for their claims.

Figure 5 reveals that the village of Gaira, located in the centre of the forest where most of the controversies are concentrated, was established before 1962, although it is true that it shows signs of spatial expansion since then. The local tribal people informed me that they need the forest because it provides them with a livelihood (for more, please see section 4, chapter 6, page 189) and they want it to be preserved. They indicated that the Forest Department's poorly planned projects, government plans to transform land use to establish security installations, building government offices, and leasing out forest lands for rubber plantations are responsible for many of the major changes. Figure 5 also highlights that the government has established an airforce firing range by clearing a large area of forest (the yellow box in figure 5). The security installation could easily have been developed on some other vacant land away from the forest or on an unused coastal island. I also interviewed local forest officials and questioned them about the purpose of clearing good quality stands (see photoplate 4 in chapter 6, page 200 and also the yellow box on figure 5) for social forestry schemes, where the goal is to develop vacant and denuded land (Gain 1994, Gani *et* al. 1990a, MoEF 1997). The local forest

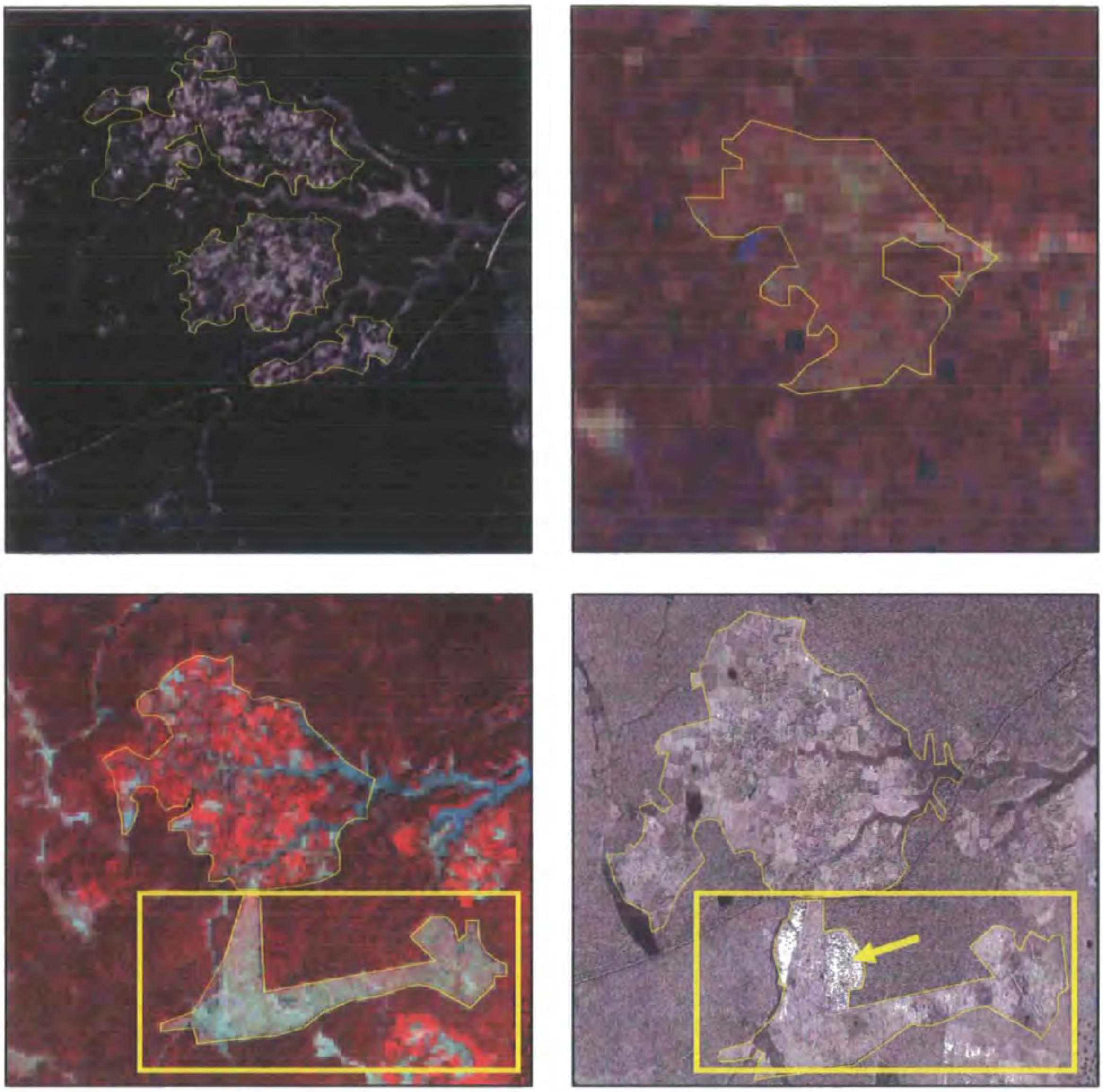


Figure 5: Temporal change of settlement (i.e. the village called Gaira) boundary in Madhupur forest; in Corona image of 1962 (upper left), in Landsat MSS image of 1977 (upper right), in Landsat TM of 1997 (lower left) and in Quickbird image of 2003 (lower right). Yellow arrow shows good quality forest stands cleared out to make room for social forestry projects by the forest department.

officials admitted their responsibility and indicated that they need to create spaces for social forestry at any cost as foreign aid has been earmarked for that. In a recent article Zimmerer (2006) has indicated how ecological conservation projects around the globe have been shaped by the policy directions and financial support of international funding agencies. In addition, the corruption of forest officials has been widely reported in national news media in Bangladesh as a major cause of deforestation in the study area (please see more in chapter 6). The local inhabitants and NGO workers reported to me that the forest officials and guards allow businessmen to bring lorries at night into the forest for illegal logging. They selectively log instead of clear cutting so that their activities cannot be detected; and this is difficult even for high spatial resolution satellites to monitor because the canopy reflectance from the upper story forest may still be similar to the previous state. Almost all of the old big trees, thus, have been completely cleared out, except close to the vicinity of the local forest offices, presumably as a façade for illegal logging further away. The government has taken no major action so far to arrest those responsible for these corrupt practices.

Estimating or assessing forest characteristics is a big challenge when it comes to issues of quality. This ambiguity creates scope for certain types of deforestation process. Selective logging, discussed before, is such a kind of activity that it might not bring sudden change in its spatial shape in the first place. Therefore, it might be misleading to give an account of forest resources without indicating the quality determinants. As the quality issues are generally neglected in forest statistics, encountering selective logging undertaken either by local people or by forest department's corruption becomes hard. This ceaseless selective logging can bring the forest to the brink of complete deforestation within a few years. Thus the processes of deforestation mostly remain unseen and the prime causes remain undefined and policy prescriptions rarely address these issues. These subtle and gradual forest changes in the Bangladesh context are different from the abrupt changes found in Amazonia (Lucas *et* al. 2000b, Nelson *et* al. 2000, Houghton 2001, Lu 2005) or South East Asian tropical forests (Foody *et* al. 2001), where massive clear cutting dominates the landscape. It can be argued that the processes and patterns of deforestation are different from one country to another, and this makes it difficult to find a generalized pattern of causes/factors applicable to all places (Lambin 1999). Lambin (1999) has suggested the need to study and monitor the pattern of change over a few decades before making any generalized inference.

It is clear that causes of forest change considered by the Bangladesh Forest Department are far from the reality. The actual causes of deforestation are ignored because of three major reasons, (i) the potential risk of maintaining illicit benefits for vested interest groups; (ii) lack of understanding of the resource stock; (iii) the lack of a long term vision in policy planning. Evidence of the flaws and failures of the forest department can be found in the fact that forest resources have depleted in the course of the many projects implemented in the area - the opposite of what was hoped. The current vocabulary, discourses/narratives about Bangladesh's forests in the national policy literatures mainly designed to serve certain vested interests, where problems are viewed and solutions are proposed as a response to serve their purpose. Political influence (in terms of laws, acts, and policies) and power are used when and where necessary to make justifications of the actions.

Robbins (2001) and Sunderlin *et* al. (2005) both have discussed the epistemological challenges in integrating geospatial technologies with political ecological research. The causes and consequences of deforestation identified in the present research are illustrated in table 1 to illustrate how political ecological explanation differs from conventional claims.

Table 1: Causes and consequences of deforestation in the study area from political ecology point of view.

Issues	Conventional Reproach	Political Ecological explanation
Main cause of deforestation	Growing number of poor	Capitalistic approach of forest management
Agent of deforestation	Smallholders/Local people	Government policy and enterprises
Driving factors	Greed of people	Policy failures, lack of accountability
Main processes of deforestation	Fuel wood collection by the local people, forest land encroachment	Conversion of forest land by the government to non-forest land use, local people
Resolving proposition	Eviction of the poor, cordoning the forest	Alternative measures that are compatible to the situation
Solution process	Policing, filling criminal cases against locals	Discussion with the stakeholders, learning lessons from the mass movement

Modified after Contreras-Hermosilla 2005.

8.3.3. Factors Influencing the Pattern/Nature of Change

The nature of forest cover change in the study area has two major dimensions, which are also actor-dependent. Changes incurred by the political decisions of Government are different from those perpetrated by local people. Major political decisions like conversion of forest land to other land use patterns (i.e. establishing security installation, or offices in the forest area, rubber gardening, converting forest lands into agro-forestry) influence forest depletion and this is one of the major causes of change in the area. Secondly, political directives to deal with long-standing land tenancy disputes with the local people by using the state power create tensions, mistrust and unrest in the area at the cost of further forest degradation. These land tenancy issues could be resolved through negotiation, properly compensating the evicted people, evaluating/examining old records, and by not settling any more Bengali people in the forest area. The Bengalis were settled as part of a government plans to undermine the dominance of the tribal population in the area. In Sarawak (Malaysia), a similar pattern is also evidenced (Colchester 1993). It is interesting to note, that the government is replacing communities in the forest area, while at the same time population pressure is pointed out as a cause of deforestation. This clearly demonstrates the inefficiency/weakness of government policy.

Implementing social forestry, and the selection of species for plantation are also responsible in shaping the forests. Remote sensing analysis was found useful in spectral separation of species patterns (figure 3a, 3b and 7, chapter 3, pages 57, 58 and 71), including the estimation of spatial and temporal change. Spatial changes are observable along the roads and building infrastructures and near the human settlements. The Bangladesh Government has declared there to be 8193 hectares (20244.23 acres) of forest land in Madhupur thana (Tangail district) and 240 hectares (593 acres) in Muktagacha thana (Mymensingh district) in a National Park. This park is the only project of the government in the area that is said to work for the improvement of forest condition, costing 1 million Bangladesh taka. But the examination of the National Park Project proposal suggests that the idea is vague, the objectives are unclear and how ideas about existing problems should be addressed before its implementation were unclear (Appendix

3). In addition, how the proposal will act in accordance with other government schemes is not appropriately outlined. The current National Park development project is in operation to develop infrastructural facilities in the forests to earn money from tourism, where forest regeneration attempts are neglected.

Sometimes local people capture forest lands or expand their existing homesteads and agricultural land with the hope that they will be able to show that the land is in their possession if the government ever carry out a land settlement programme in future to resolve tenancy disputes. Some of the non-local groups see forest land as easily available land to capture for establishing industries or other business with or without the support of government. Although it depends how much power (political, financial, muscle) they hold, and the connection/communications they maintain.

8.4. Integrating Science and Social Science into the Decision-Making Process

In my research, science, in the form of remote sensing techniques, has provided technical answers and insights on forest resource mapping issues and indicated specific areas to be addressed. The information-base emerged from this study is potentially useful for policy makers to take efficient resource management decisions. Data on the rate, pattern and process of spatial and temporal change of the forest resources, impacts of current interventions in the area, and information on health, structure and species patterns of trees may all help the planners and resource managers to make informed choices with minimum uncertainty. On the other hand, the explanations adduced through the theoretical support of political ecology have highlighted the inherent historical, socio-political issues that pose threats to adopting justified resource management options. Scientific information provided the interlinking evidence of impacts between social actions, political decisions and resource depletion. Scientific exercises at the local level demonstrate that large scale information can give a clear insight on the issues and impacts, facets of the problems that broad categorical information generally fails to see.

Forest resource assessment and/or rehabilitation projects in Bangladesh are mainly based on broad categorical information. Noss (2004) observed that management decisions are almost always made with inadequate information in tropical countries. Mayaux *et* al. (1998) added that definitions and directions of appropriate tropical forest policies must be supported by reliable and up-to-date information about forest distribution and health. Lack of this information on land cover may cause costly failures to many forest rehabilitation projects in the tropics (Apan 1997). The same types of frustrations/uncertainties are also expressed in government planning reports (Gani *et* al. 1990a, MoEF 1997) in Bangladesh. Sometimes the need for the assessment of interventions is ignored over financial aid from foreign sources. For instance, social forestry/agroforestry programmes (involving foreign currencies) identical to global models may not suitable for Bangladesh as issues, problems, differ between boreal, temperate and tropical forests and even within these biomes (Szaro *et* al. 2005). These differences indicate the need for objective information so that problems can be perceived first before prescribing any solutions. Forest resources in Bangladesh are still viewed as goods of consumption; the non consumptive services (i.e. biodiversity maintenance, role in making balance in the ecosystem) are generally not taken into account. This has also happened due to the lack of scientific information on various different environmental parameters. Giest (2001) and Kinzig *et* al. (2003) point out that our existing models of resource management should be improved to make a balance between social, economic, physical-biological and ecological models. An integration across the disciplines, therefore, is needed in order to synthesize pertinent information to improve the conventional models, as singular disciplinary analysis may not capture all dimensions of the problem. The amalgamation of science (i.e. remote sensing) and social science (i.e. political ecology) has been very valuable in assessing the problems in deciduous sal forests in Bangladesh so that problems can be properly addressed in the policy field.

8.5. Scale, Scope and Complexity (Impact of Scale and Resolution)

The study of global environmental change is now well established in the geographical research domain (Liverman 1999). But recent deforestation problems all over the world, especially in the global south require us to look at the problems from the bottom in order to understand the actual processes and identify the agents that determine change because the knowledge of the intellectual community concerning the distribution, quality, change and social dimensions of forest in the tropics is limited (Achard 2002). One challenge is that, it is difficult to theorize or come to aggregate conclusions about many issues of the human use of natural resources at the local level because of the difficulty of measurement (Matthews and Herbert 2004). Fine spatial resolution images for measurement and analysis might be an answer in this regard, to detect generally unseen interactions of different agents/social drivers that cause land cover change. Fine spatial scale also can help to find out specific indicators of human detrimental effects (with indications to further damage). It is important to identify those (so-called development) indicators because there is often a time lag between a development and its negative environmental impacts. In that regard, developing indicators might help to identify and monitor impacts before excessive damage arises (Foody 2003, Hall 2001). This scale issue can also be extended to link with local economies leading to the structural representation of the space containing natural landscape and human organization. The recent advances in remote sensing technology are enabling new science and products that offer a great promise both to natural (Katila and Tomppo 2001, Tomppo 1999, Tuomisto *et* al. 2003) and social scientists, policy planners. The sharing of data can also create a common ground of research between human and physical scientists. The results of my study show that this new domain also puts geography in the forefront in human- environment research. The statistics generated at finer scales (see chapter 3 and 4) are not only self explanatory but also give us a chance for testing hypotheses. This opportunity of cross-checking may also bring some accountability and resolve complexity among the authorities who are officially responsible for its governance.

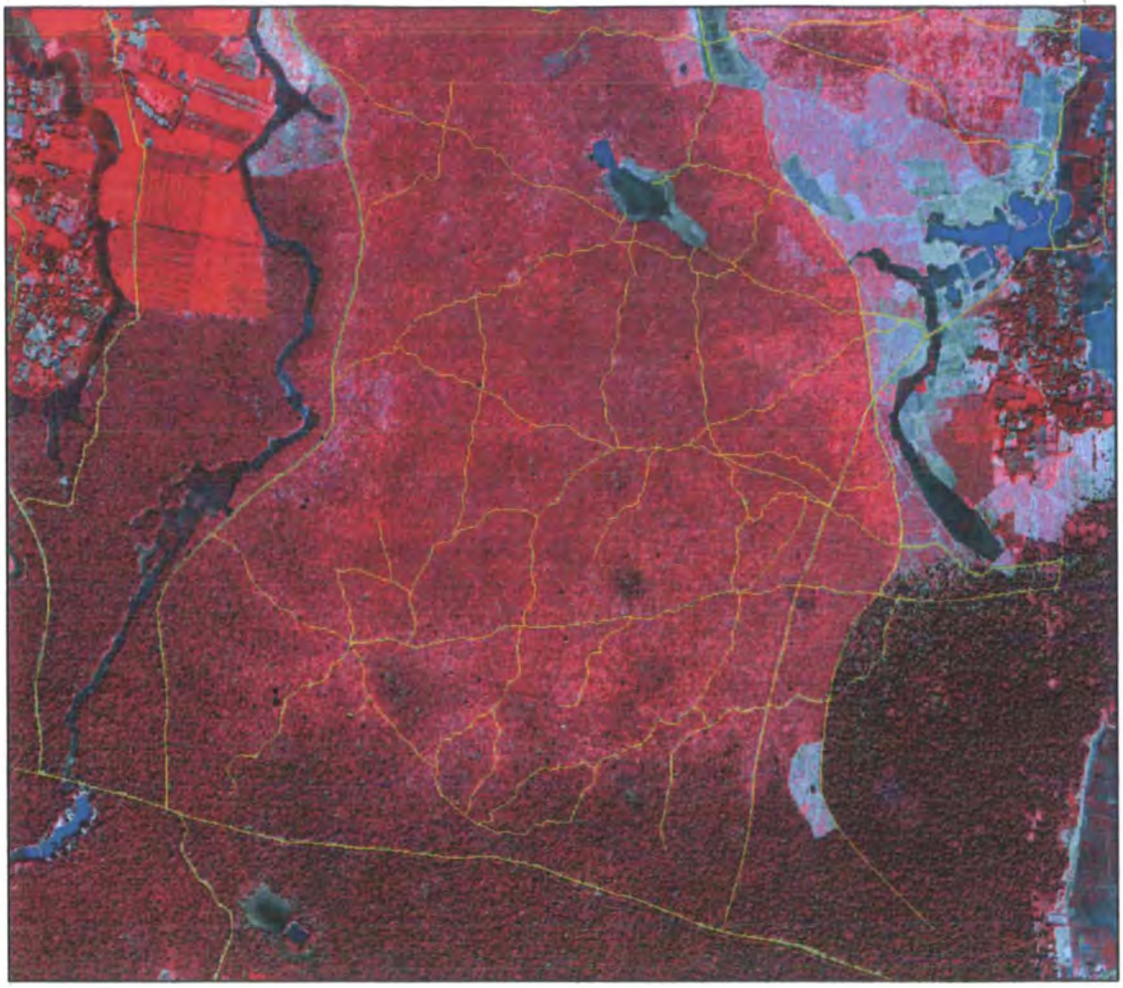


Figure 6: High spatial resolution Quickbird satellite data (October 2003) shows forest landscape in the study area with strong signs of cultural phenomena. Criss-crossed walking trails are made in the forest to facilitate forest clearance.

8.6. Limitations of Remote Sensing Techniques

It should be remembered that the use of remote sensing data has some limitations (Atkinson 2000). Conventional techniques of remote sensing data analysis are sometimes only limited to land cover transformations, which has limited value (Foody 2001), especially in tropical forest. Sometimes remote sensing techniques useful in boreal forest inventory and research might not appropriate for tropical forest (Lambin 1999). For instance, Donoghue (2002) suggested that the strength of model results of forest biophysical variables in relation to Landsat data (comparatively coarse spatial resolution data compared to Ikonos data) is almost similar while using high spatial resolution Ikonos satellite data for the same purpose. But in the case of Madhupur forest, high spatial resolution Quickbird satellite data shows stronger association with stand structure data than that with Landsat data (see chapter 4, for explanations). Even the areal forest estimation using Landsat ETM+ data (2003) is found to be different when using high spatial resolution Quickbird satellite data (e.g. 1270 hectares of closed canopy forest cover revealed in Landsat data and 594 hectares in Quickbird data). This difference may raise serious disputes if the underlying cause of it is not understood or declared (please see chapter 3). Figure 10 in chapter 3 (page 77) clearly depicts the problems related to spatial resolutions of image pixels. Field assessments are therefore vital (Atkinson 2000) in using remote sensing techniques for forest resource assessment. The application of remote sensing is sometimes problematic in the tropics because of its complicated stand structure and abundant species composition in its forests (Nelson *et* al. 2000). The cost of satellite data and associated field expenditures, inadequate resources (hardware, software, skilled manpower) also sometimes puts up barriers in its use in the tropical forest applications. Despite all of this, remote sensing data have demonstrated a high potential for use at different spatial and temporal scales in a tropical country like Bangladesh. It also may provide strong information on human and environmental indicators of change (Hall 2001) and any potential change that may help decision-makers for managing of natural resources appropriately (Schultink 1992, Chen 2002).

8.7. Conclusion

State-of-art remote sensing techniques, along with political ecological explanations of forest degradation, have also been used by some other researchers in different parts of the third world. It is becoming a common toolkit of political ecologists interested in understanding the multi-scale dynamics of nature-society relations (Zimmerer and Bassett 2003, Robbins 2004). McCusker (2003) extensively used GIS and remote sensing techniques in land use, land cover change study in South Africa. She commented that most of the land cover studies relied on GIScience and produce representations of global/regional change that are poorly linked with human-environment landscape dynamics. In that regard, my research has provided evidence of forest cover change in the study area over time and demonstrated the ability of remote sensing techniques to develop model predictions of the forest structural variables. The research has provided comprehensible information with reasonable accuracy for contesting the government forest statistics and it is hoped that this will help to resolve some uncertainties around forest issues, and provide a basis for right and decent policy planning. Sayer *et* al. (2005) recently mentioned that 'the difficulty lies not so much in developing new ideas, as in escaping from the old ones'. Therefore, although the techniques and tools are available, the question is how these can be practically deployed to contest conventional modes of problem representation and how to use these tools to manage the forest resources more efficiently.

Chapter 9
The Summary and Conclusions

This chapter summarizes the major findings of the research and draws conclusions about its practical implications.

9.1 Introduction

The aim of the thesis was to assess the deciduous sal forest resources located in the central parts of the country to enquire three major questions, (i) what is the current physical condition of the forest? (ii) what is the changing pattern of forest resources? (iii) what are the social factors that influence change? Remote sensing data and methods were used for the first two sets of queries, while a political ecological approach was employed to help locate the root causes of change. The results indicate that remote sensing techniques can be used to improve the forest statistics on the areal extent and the distribution of forest cover. While this point has been made by many other authors e.g. Lambin *et* al. (2001, 2003) this study is among the first to demonstrate the value of remote sensing for forest resource mapping in Bangladesh. Another novel aspect of this work is the assessment of forest structural attributes from new high spatial resolution imagery. Although reflectance modelling is well known in Australasia, Europe and North America it has not been attempted before in Bangladesh. Remote sensing becomes a very attractive tool for resource assessment and monitoring, not only can maps and statistics of change be produced cheaply and easily, the data contain information about the quality of the forest resources so that mature intact forest can easily be distinguished from those degraded by selective and often illegal logging. On the other hand, the use of the theoretical framework of political ecology helped to identify why and how the social actors within the socio-political and cultural regime use natural resources for their own interests (Sunderlin *et* al. 2000, Lambin *et* al. 2001, Smith *et* al. 2003). This attempt to integrate physical and human geography is considered to be a timely when social variables and actions profoundly impact on the physical properties of natural resources in the study area. This methodological integration may also bring transparency and efficiency to forest governance (Chowdhury 2006).

The findings of the local-scale investigation in Madhupur forest indicates there is a big gap between the real condition of the forest, driven by social dynamics and the national-level representation of the problem. These gaps or uncertainties sometimes mislead policy and management action. In addition, the research demonstrated that a lack of awareness of inter- and intra-scale connections of actors and functions can instigate inappropriate policies/projects. For example, official forest statistics may correctly identify areas as wooded but this may not accurately convey its condition in resource terms; a heavily degraded forest may not qualify to be grouped as a forest if quality concerns are raised. Sometimes barren lands are also included as forests by local foresters in tropical forest estimation (Zhu and Waller 2003). National level forest statistics in Bangladesh are the aggregation of local scale accounts, forwarded by the local level forest officers, who are not trained to consider quality issues. In that regard, local-scale forest assessment is vital for identifying physical and social properties and indicators for sound management.

9.2 Reviewing the Objectives of the Work

Aim 1: *Assess the land area covered by moist deciduous forest resources and measure change over a forty year period.*

Different types of satellite remote sensing sensors (i.e. Corona, Landsat, Aster, Quickbird and IRS Liss-III) have been used to help map forest change between 1962 to 2005. The historical images were interpreted and classified on the basis of spectral and tonal match (mainly to identify forest, non-forest areas); landuse patterns were checked in consultation with key informants (mainly old people) living in the forest. The classification of Landsat ETM+ and Quickbird data from 2003 were supervised with field data collected in the same year. A Post-classification approach was used to quantify forest change. Spectral change detection analysis methods such as NDVI differencing were avoided because it was difficult to undertake radiometric correction in those multi source, multi date satellite data.

Field data were also used to assess the current structural properties of the forests in the study area. High spatial resolution Quickbird satellite data showed some promise in this respect because its finer spatial pixels are able to represent spectral signals from field plots. Landsat data, on the other hand, showed limited success in assessing forest biophysical variables probably because comparatively large size pixels encountered more variability than the corresponding field sample. This problem could be resolved by enlarging the sample plots, but the consequence would be very imprecise estimates of forest structure and condition. In addition, the local situation where logistical support is necessarily limited and there is political unrest and a lack of law and order make it impractical to undertake large time consuming field surveys.

This is another reason why remote sensing can compliment and add value to traditional forest mensuration methods. But we must be careful before recommending this approach as optical remote sensing can not see the trees through canopy cover. In addition sample plots were not big enough to claim that this modelling approach may work in other parts of forests as well. But the maps derived from the model agreed with the raw image (appendix 8). The results also indicate the poor current condition of forests in quality terms.

Aim 3: *Better understand the underlying social causes of forest land degradation.*

This study attempted to describe and understand the social factors/variables associated with forest change in the study area. Political ecology, employed to assess the social variables, was found to be useful to detect the socio-political forces and underlying causes and drivers of forest change such as like historical legacies of land tenure problems, ineffective policies, and illegal logging/corruption. This theoretical framework also indicated why and how certain arguments and statistical representation of forest related issues in government literature is formulated to secure their vested interests. The study examined the ongoing social forestry programmes in the area and found that such programmes are not well accepted by most of the local people (because of Acacia tree species selection for the project, unclear contractual agreements and recipient selection methods are skewed to wealthy local groups etc.). It is evidenced that forest department clear out natural forests to make room for this social forestry programmes, that eventually cause deforestation. In addition, government plan to convert land use patterns to other land use types impacted on the forest.

9.3 Major Research Findings

The findings of the research can be grouped as follows; the first two are focusing on the findings of the techniques/methods employed in this study. The third section points to the integrative arguments.

9.3.1 Remote Sensing Findings

- Corona satellite photography from 1962 was very helpful to look into the past and to provide a baseline for assessing temporal change. Aerial photographs could be used instead but use of aerial photographs in Bangladesh is still restricted by the Government. This restriction of past data/record use (i.e. the aerial photographs) severely limits longtitudinal studies of forest change the researchers community or any NGOs. Therefore, transparency of government actions can never be assessed. In that regard, application of declassified high spatial resolution Corona programme photography filled that data gap.

- Within the defined study area in Madhupur thana the forest cover reduced from 3826 hectares in 1962 to 3573 hectares in 1977, 1801 hectares in 1997, 594 hectares in 2003. The accuracy of the supervised classification of Quickbird data is 78.04 percent (kappa is 0.72), where accuracy of Landsat ETM+ data is 84.26 pecent (kappa 0.81). Fine spatial resolution satellite imagery (i.e Quickbird data) showed a tendency to receive signals from the ground vegetation through the canopy gaps. This may cause mis-representation of forest signals in the spectral properties, the problem was addressed in chapter 4.

- Spectral reflectance data from remote sensing successfully discriminated different types of cover types in the study area (i.e. natural forests, rubber plantation, argo-forestry etc.).
- Most types of remote sensing could identify the impact of development planning/infrastructure, settlement on the forest. Very detailed information that appeared to be associated with illegal logging could be clearly identified on Quickbird image data.
- The results indicate that determining image spatial resolution is an important factor according to the scale of any research. Comparatively coarse resolution satellite data (like Landsat ETM+) showed limited success to work at local scale analysis, sometime it may lead to generate imprecise information.
- Current and reliable (cartographic) map data were derived using remote sensing data.
- Sample design and ground survey methods were tested and found useful to conduct forest inventory surveys and could be transferred to the forest industry to measure timber resource and to authorities and sponsors to monitor grant schemes.
- Forest structural variables show strong relationship with one another (e.g. dbh versus tree height) except the tree density. It is also evident that the correlation values significantly differ when sample plots are grouped according to its properties (e.g. closed canopy, open canopy, poor quality forest/sal tree saplings).
- Near Infrared band of Quickbird data (Band 3) showed strongest association with dbh, height and volume variables. The strength of the association is also variable according to the stand quality groupings.

- Regression equation developed for closed canopy forests (as it is the true representation of Shorea robusta forest) in relation to spectral information is used to predict forest variables.
- The *R-squared* values (0.66 and 0.79) of predicted results of tree height compared to field estimations suggests that forest inventory can be effectively carried out using high spatial resolution satellite data in tropical forests.

9.3.2 Findings of Political Ecology

- It is revealed from policy analysis, interviewing local people that unresolved land tenancy disputes created mistrust and antagonistic relation between the forest department and the local inhabitants in the area and causing deforestation. This land tenancy dispute rooted in the colonial times is dealt by the government using state power (like forceful eviction, filling court cases, calling them illegal occupiers). At the same time, introducing new settlers (through the land reform policy) into the area to undermine the tribal dominance clearly indicates incompetence to handle the problem. This new settlement scheme fuelled forest change in different ways.
- Government decisions to convert landuse pattern (building security installations, office parks, allowing industries to set) are responsible (see chapter 6 and 7 for more) in the area for forest clearance.
- Pervasive corruption of some personnel in the forest department (and the lack of government scrutiny) has impacted on the natural forest resources.
- Inappropriate programme implementation (like agro-forestry projects, where Acacia tree species are recommended, or the national park and eco-park project, are responsible for big disputes in the area) without consulting

stakeholders and without conducting any compatibility assessment, mislead the authorities to act against the sustenance of the natural forest.

- The structural inequalities in society that cause poverty compel the people to create pressure on the forest resources. Without addressing these issues, sound forest management is difficult, and a number of respondents during the field visit informed me that they migrated in the area in the belief that they could cope with their economic setbacks by using forest resources (no matter whether legal or illegal) and by capturing forest lands, illegal logging etc.
- There is impact on the forest from the establishment by businessmen of wood-based small industries (wood-saw mills), traditional brick-burning kilns, and rubber gardens in the close vicinity of forests through political influence and power.
- The study has identified that social movements, NGO activities, and the media have helped to bring forest problems to light.

9.3.3 The Fallacy of Forest Management: Contesting with Remote Sensing and Political Ecological Integration

Remote sensing data and techniques provided evidence of forest clearance and forest degradation, while political ecology encompassed the ecological and political dimensions of environmental breakdown issues. Environmental degradation might be caused by natural or social factors. Sometimes, natural factors impact without human interference. But, in the study area, the results suggest that natural causes of environmental degradation are far from the reality. The causes of forest degradation are mainly anthropogenic, historical, the outcome of policy failures, and a pervasive corruption of the state forest department (dysfunction of the government). The forest clearance during the last couple of decades, revealed in the remote sensing analysis, is mainly caused by the factors that have emerged from the political ecological actions/decisions, although it is difficult to establish a one-to-one relationship between the pattern and process of change. Remote sensing techniques, through statistical modelling, have shown quality degradation of forest, signs of areas cleared for the airforce firing range and social forestry, conversion of forest land to rubber plantation, evidence of engulfing forests with the expansion of settlements, and indications of the influence of infrastructure. The cartographic map products could be used by the resources managers and planners as a tool to assess, plan, and monitor processes and progress. The field methods and statistical modelling used in this study can also be transferred to the industry to be used as a practical tool to update the forest statistics in Bangladesh. Applications of remote sensing by different stakeholders (i.e. by researchers, watchdog NGOs/activists, media, policy planners, resource managers) may also bring transparency to the actions of sound forest management.

9.4. Geographical Significance of the Work

The approach of this research is not interdisciplinary (the linking of moderate integration of disciplines), nor transdisciplinary (the high level, fused integration of disciplines); it rather adopted methods that are already established within the realm of geography. Remote sensing and political ecology have in practice been within geography for the last twenty years, though their integration is not common (Johnston 2002, Massey 1999, Rhodes 2004, Skole 2004). Even within the discipline of geography there has been a polarization in the research agenda, for instance across the human/physical divide but also between the increasingly conceptually-driven, qualitative style of fieldwork that has become popular in human geography in recent years and the technically and quantitatively centred approach of sub-disciplines such as remote sensing and Geographical Information Science. The argument/rationale, language, and attitudes amongst scholars are now so divergent that one could justifiably identify several mutually exclusive epistemological strands in geography (Thrift 2002). Thrift (2002) in a recent article *The Future of Geography*, warned geographers about the continuing ontological and epistemological divergence of physical and human geography (Skole 2004, Matthews and Herbert 2004). The danger lies in the fact that physical geography rather finds allies in Earth or natural sciences than in human geography. At the same way, human geographers are close to sociology or anthropology. Sometimes, they do not understand each other's language and methodology. Thrift (2000, 2002) criticized this polarization of physical and human geographers and stressed the need for unity, although it can be argued that the polarization has at least given both sides the credibility of a specialization. But it is sure that the discipline is more robust than ever before in qualitative and qualitative tools that are necessary for efficient geographical experiment. In that perspective, an effective mixture of physical and human geography (what this study undertook) is a timely response to demonstrate how these two wings can address human-nature problems in the best possible way. The blend of these quantitative and qualitative approaches has helped to understand the spatial and temporal dimensions of forest environments and social processes, since the problems arise from the intertwined factors related to time, space and society.

9.5. Future Research Directions

The research would be complete if it could cover most of the deciduous forest resources distributed in the whole Madhupur tract area covering all three districts (i.e. Dhaka, Gazipur and Tangail). That would give us a complete picture of the deciduous forest resources located in the central parts of the country as resource managers, planners, researchers at different scales are lacking real forest information and map products to assess the condition of the forest. Actual information about forest resources may also help to deploy area specific plans (based on regional need), not having a single prescription for all the forests.

The forest in Madhupur is heavily degraded and that hinders appraisal by the comparatively coarse resolution of Landsat satellite data. The present study found it difficult to get representative forest sample plots with sufficient tree stands to appraise the spectral properties of Landsat data. But Donoghue and Watt (2002) found, while studying British upland forests, no significant difference in model results between Landsat data and high spatial resolution Ikonos data, as the spectral properties are identical in both the datasets. This suggests that Landsat data (or data with a similar spatial resolution) might be suitable for assessing structural properties of forest in the tropical countries as well. Therefore, a forest inventory exercise using Landsat data in areas where the condition of the forest is better could give some indication about its capability to assess forest biophysical properties. It can be noted, in this regard, the new high spatial resolution satellites are planned, including the Indian CARTOSAT and this will enhance the potential of remote sensing for resource assessment by providing more access to data. Consequently, there is a need to continue remote sensing research to better understand how these data can be used and what their limitations are in complying tropical forest environments.

There is a clear gap in cross-disciplinary/cross-methodological assessment of environmental crises. Environmental problems in Bangladesh are viewed within a narrow focus where new techniques or important aspects of a problem may be missed. More research, therefore, is required by integrating methods to identify both the proximate and distant sources of crises including the underlying driving forces that impact on the natural resources. It is revealed in my research that government actions and policies are still induced by neo-colonial motives, where revenue earning is set as the prime objective in forest management, even though in those cases where forests/natural resources cannot bear that. The lazy, stereotypical explanations of population pressure or theft by local people are seen as the major factors of change but the real causal factors are neglected.

This study is based on a single field visit undertaken in 2003; more field visits would be useful to assess the outputs in greater depth. In addition, the field visit occurred at a time when there was violence over the eco-park project between the government between local people and Bangladesh forest department. Avoidance of any kinds of hostility during field work or (any phase of work) is necessary to produce good piece of work.

9.6 Conclusion

This study analysed the problems associated with deciduous forest resource mapping and management in the central parts of Bangladesh. The problems are assessed quantitatively in terms of forest cover change and forest structural properties with the aid of remote sensing. It also accommodates human-environment interface research approach (using political ecology) to grasp the societal values, choices, divisibility (of property/resource distribution/ownership), historical legacy of land ownership, power relations and conflicts, struggle over natural resources and movement of the local people. These factors are interweaved and rooted in the process of deforestation in the study area. Forest protection or management is, therefore, almost impossible if these issues are left out from the agenda and if the actual information about the forest is not known. It is hoped that the unification of these two approaches is a timely response to Thrift's (2002) frustrating statement - '*human and physical Geography are splitting apart*'. This integration also demonstrates that the integrative approach can help to address problems at human-environment interface more effectively.

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Appendix 1

Survey Questionnaire

1. Name of the respondent:
   Address:
   Occupation:
   Education:
   No of family members:

2. Are you
   - ☐ immigrant in this area or
   - ☐ permanent resident

   a. if immigrant, what was the reason for immigration
   - ☐ due to the migration of the ancestors
   - ☐ self decision to migrate this place for economic betterment
   - ☐ others

   b. where from have you migrated?

3. a. How much land you posses
   - ☐ for homestead (settlement)
   - ☐ agriculture (byde and chala land)

   c. What kinds of agricultural crops you grow
   - ☐ in byde land
   - ☐ in chala land

   d. do you have any fruit/vegetable garden in the forest land:
   - ☐ yes
   - ☐ no

   if yes, a. what kind of garden is it?

   b. had you had to cleared out forests to make room for cultivation.

   e. What was the source of your land ownership?

Source	Settlement	Agricultural land
Purchase		
Inherited from the ancesters		
Others (lease, encroachment etc.)		

   f. if the land is purchased,
   - ☐ from whom have you purchased
   - ☐ what was the landuse pattern before you purchase

4. What kinds of trees can be found in this forest and which plant species are the most valuable, why/how?

5. Please define the roles of forest lands/forest products to support your livelihoods.

6. What kinds of projects are being implemented in your area (e.g. woodlot plantation, agroforest, strip plantation etc.)

    a. how do you participate in the projects?

    b. are you happy with the benefit-sharing agreements with forest department?

    c. did you receive the benefits promised?

    d. how do you assess the success of the social forestry projects (e.g. is it beneficial for forest or caused deforestation)?

7. Please comment on the following issues,

    a. what are the major reasons you consider that caused deforestation

    b. who are responsible for deforestation

    c. what are the major impacts of deforestation on the society and how do you cope with the current situation?

    d. how the remaining natural forests can be protected?

Thanks for your time.

Appendix - 2

Field Data on Forest Variables. Collected in November 2003-January 2004.

Plot No	Manage -ment Class*	Unders tory Veg**	DBH (cm)	Height (m)	Basal Area (sq.m/ha)	volume (cu.m./ha)***	Tree Den (trees/ha)	Age
1	1	A	44	20	15.07	120	40	40
2	2	A	20	17	20.09	125.44	640	15
3	2	A	16	13	15.27	85.12	760	12
4	1	A	56	23	29.54	314.28	120	50
5	1	A	48	20	18.56	213.24	120	40
6	2	P	20	15	8.79	54.88	280	15
7	2	A	23	16	14.94	111.6	360	15
8	2	A	21	14	16.61	119.52	480	12
9	2	A	19	13	14.73	101.92	520	12
10	2	A	36	16	25.32	173.6	560	18
11	2	A	22	19	13.68	89.64	360	15
12	2	A	20	16	9	27	520	15
13	2	A	12	8	8.59	34.2	760	25
14	3	P	19	13	12.6	33	560	15
15	3	P	18	12	14.24	84	560	15
16	2	P	14	12	9.84	51.2	640	10
17	2	P	13	10	9.55	57.6	720	15
18	2	P	13	9	10.08	120	760	30
19	2	P	12	9	8.59	34.2	760	15
20	1	A	14	11	9.23	48	600	25
21	1	A	13	11	9.02	54.4	680	30
22	1	A	16	13	13.66	76.16	680	25
23	2	A	28	13	12.17	49	360	10
24	2	A	26	16	8.89	33	400	20
25	2	P	15	13	9.9	62.72	560	25
26	2	P	14	10	11.07	57.6	720	10
27	2	A	15	13	10.6	67.2	600	10
28	2	A	15	12	9.89	140	560	10
29	2	A	16	14	12.05	67.2	600	10
30	2	A	10	8	5.65	24.48	720	10
31	1	A	30	16	10.61	45	280	25
32	1	A	46	18	15.42	190	120	40
33	3	P	4	3	0.45	1	360	2
34	3	P	5	3	1.25	1	640	10
35	2	P	5	3	0.86	1	440	5
36	2	P	4	4	0.6	1	480	2
37	2	A	18	16	16.27	95.44	640	15
38	2	A	17	13	17.24	120.12	760	12
39	2	A	16	14	15.27	97.04	760	13
40	2	A	10	8	5.33	56.87	680	10
41	2	A	15	13	11.05	67.2	600	10
42	2	A	16	13	10.59	71.11	580	12
43	2	A	17	13	12.3	69.78	580	12
44	2	A	22	16	10.61	152.32	280	25
45	2	A	33	18	19.75	180	280	15

46	2	A	12	9	9.02	54.4	680	12
47	2	A	13	10	9.23	48	680	12
48	2	A	14	9	9.23	51.03	600	15
49	1	A	28	13	12.57	37	360	12

* 1- Closed canopy sample plots, 2- Open canopy sample plots, 3- Poor quality sample plots/Saplings.

** A-Absent, P-Present

*** Volume table was calculated using Bangladesh Forest Department's volume chart for *Shorea robusta* tree species.

Appendix – 3

Name of the key persons, who were interviewed during the field visit:

1. Mr. Eugine Homrich, Misister, Jalchatra Church, Madhupur.
2. Head Teacher, Jalchatra High School.
3. Mr. Eunus, Local Businessman, Madhupur.
4. Rabindra Nath Adhikari, Forest Officer, Tangail Forest Division, Tangail.
5. Divisional Forest Officer (DFO), Tangail Forest Division, Tangail.
6. Assistant Conservator of Forest (ACF), Rasulpur Forest Office, Madhupur.
7. Forest Ranger, Rasulpur Forest Office, Madhupur.
8. Divisional Forest Officer (DFO), Dhaka Forest Division, Dhaka.
9. Babul Nokrek, Local tribal/community leader.
10. A number of local elderly people including Bengali and tribal people.

Appendix 4

Table 1: Summary of regression models used to estimate forest dbh from Quickbird Satellite Data.

No Predicttors	Model	Image Band	DBH*		Equations
			R^2	RMS Error (cm)	
Closed Canopy Forest Sample Plots: n= 9					
1	1	1	0.2077	15.518	dbh = 1246.387 – 5.804925 QB_b1
	2	2	0.4757	12.923	dbh = 586.9386 – 2.105246 QB_b2
	3	3	0.6666	10.066	dbh = 710.028 – 5.57683 QB_b3
	4	4	0.5942	11.106	dbh = 191.072 – 0.2873577 QB_b4
2	5	1 2	0.4351	13.103	dbh = 818.1582 -3.325796 QB_b12
	6	1 3	0.5264	11.998	dbh = 1152.936 – 6.778457 QB_b13
	7	1 4	0.5918	11.139	dbh = 246.5632 – 0.5626476 QB_b14
	8	2 3	0.5553	11.625	dbh = 651.0681 – 3.214665 QB_b23
	9	2 4	0.5991	11.039	dbh = 245.4039 – 0.5223652 QB_b24
	10	3 4	0.6108	10.877	dbh = 220.5174 – 0.5584987 QB_b34
3	11	1 2 3	0.5132	12.164	dbh = 831.9057 – 4.037808 QB_b123
	12	1 2 4	0.5958	11.084	dbh = 294.4783 – 0.7673338 QB_b124
	13	1 3 4	0.6077	10.92	dbh = 273.7049 – 0.820069 QB_b134
	14	2 3 4	0.6127	10.85	dbh = 270.2966 – 0.7616611 QB_b234
4	15	1 2 3 4	0.7018	9.52	dbh = 302.1377 – 0.9461637 QB_b1234
Open Canopy Forest Sample Plots: n= 36					
1	1	1	0.1045	6.3562	Dhb = 257.9978 – 1.155053 QB_b1
	2	2	0.1993	6.0104	Dbh = 160.4333 – 0.5414868 QB_b2
	3	3	0.1534	6.1803	Dbh = 124.5852 – 0.8832714 QB_b3
	4	4	0.0956	6.3878	Dbh = 47.35667 – 0.0540418 QB_b4
2	5	1 2	0.1825	6.0741	Dbh = 205.4827 – 0.7960676 QB_b12
	6	1 3	0.1408	6.2262	Dbh = 193.1032 – 1.06584 QB_b13
	7	1 4	0.1	6.3722	Dbh = 58.43611 – 0.1075743 QB_b14
	8	2 3	0.1863	6.059	Dbh = 149.9879 – 0.6878249 QB_b23
	9	2 4	0.1117	6.3306	Dbh = 60.21409 – 0.104557 QB_b24
	10	3 4	0.1025	6.3635	Dbh = 53.05376 – 0.1054931 QB_b34
3	11	1 2 3	0.2209	5.929	Dbh = 175.4076 – 0.7972957 QB_b123
	12	1 2 4	0.1151	6.3185	Dbh = 70.49357 – 0.1550149 QB_b124
	13	1 3 4	0.1063	6.3499	Dbh = 63.64468 – 0.156846 QB_b123
	14	2 3 4	0.1169	6.3121	Dbh = 64.98254 – 0.1517768 QB_b234
4	15	1 2 3 4	0.1198	6.3017	Dbh = 74.73143 – 0.1995792 QB_b1234
Sample Plots Representing Sal Tree Seedlings: n= 4					
1	1	1	0.8321	4.0671	Dbh = 669.1007 - 3.121246 QB_b1
	2	2	0.9670	1.8041	Dbh = 384.3268 – 1.351003 QB_b2
	3	3	0.9733	1.6205	Dbh = 281.7814 – 2.143577 QB_b3
	4	4	0.5958	6.3101	Dbh = 57.44281 – 0.0717253 QB_b4
2	5	1 2	0.9512	2.123	Dbh = 484.2426 – 1.942851 QB_b12
	6	1 3	0.9331	2.5669	Dbh = 447.556 – 2.589604 QB_b13
	7	1 4	0.6058	6.2312	Dbh = 71.65316 – 0. 1413334 QB_14
	8	2 3	0.9737	1.6084	Dbh = 346.1649 – 1.664784 QB_b23
	9	2 4	0.6261	6.0689	Dbh = 75.1012 – 0.1387913 QB_b24
	10	3 4	0.6169	6.1426	Dbh = 65.48917 – 0.1408486 QB_b34
3	11	1 2 3	0.9614	1.9508	Dbh = 421.602 – 2.007885 QB_b123
	12	1 2 4	0.6348	5.9977	Dbh = 88.53526 – 0.2050288 QB_b124
	13	1 3 4	0.6260	6.0693	Dbh = 79.27894 – 0.2080571 QB_b134
	14	2 3 4	0.6448	5.915	Dbh = 82.44452 – 0.2041392 QB_b234
4	15	1 2 3 4	0.6527	5.8488	Dbh = 95.46442 – 0.2679839 QB_b1234
** dbh is considered as dependent variable.*					

Table 2: Summary of regression models used to estimate forest height from Quickbird Satellite Data.

No Predicttors	Model	Image Band	Height*		Equations
			R^2	RMS Error (cm)	
Closed Canopy Forest Sample Plots: n=9					
1	1	1	0.2116	4.14	Height = 344 – 1.570541 QB_b1
	2	2	0.5617	3.094	Height = 177.5251 – 0.6132085 QB_b2
	3	3	0.6834	2.62	Height = 199.9387 -1.513732 QB_b3
	4	4	0.6863	2.61	Height = 61.71823 – 0.0827924 QB_b4
2	5	1 2	0.5040	3.29	Height = 242.7033 – 0.9595344 QB_b12
	6	1 3	0.5389	3.17	Height = 319.9315 -1.83852 QB_b13
	7	1 4	0.6821	2.63	Height = 77.64229 – 0.1619398 QB_b14
	8	2 3	0.6251	2.86	Height = 191.9599 – 0.9142873 QB_b23
	9	2 4	0.6935	2.58	Height = 77.43833 – 0.1506645 QB_b24
	10	3 4	0.7011	2.55	Height = 70.03078 – 0.1604033 QB_b34
3	11	1 2 3	0.5724	3.05	Height = 242.3529 – 1.143147 QB_b123
	12	1 2 4	0.6884	2.60	Height = 91.52089 – 0.2211095QB_b124
	13	1 3 4	0.6952	2.57	Height = 85.24187 – 0.2353076 QB_b134
	14	2 3 4	0.7051	2.53	Height = 84.41814 – 0.2190429 QB_b234
4	15	1 2 3 4	0.8071	2.05	Height = 93.54359 – 0.2719922 QB_b1234
Open Canopy Forest Sample Plots: n=36					
1	1	1	0.0557	3.6218	Height = 109.9776 – 0.4678559 QB_b1–
	2	2	0.2865	3.11483	Height = 107.7802 – 0.3602243 QB_b2
	3	3	0.2049	3.3233	Height = 81.36038 – 0.5664819 QB_b3
	4	4	0.1884	3.3577	Height = 36.00759 – 0.0420962 QB_b4
2	5	1 2	0.2234	3.2844	Height = 128.0695 – 0.4887012 QB_b12
	6	1 3	0.1436	3.4491	Height = 111.0476 – 0.597286 QB_b13
	7	1 4	0.1880	3.3585	Height = 43.8839 – 0.0818379 QB_b14
	8	2 3	0.2617	3.2025	Height = 99.81215 – 0.4523044 QB_b23
	9	2 4	0.2093	3.3143	Height = 45.1767 – 0.0793977 QB_b24
	10	3 4	0.1956	3.3427	Height = 40.00187 – 0.0808767 QB_34
3	11	1 2 3	0.3119	3.0917	Height = 116.812 – 0.5257214 QB_b123
	12	1 2 4	0.2075	3.318	Height = 52.21257 – 0.1154825 QB_b124
	13	1 3 4	0.1945	3.345	Height = 47.37062 – 0.1177219 QB_b134
	14	2 3 4	0.2139	3.3046	Height = 48.37211 – 0.1139089 QB_b234
4	15	1 2 3 4	0.2117	3.3092	Height = 54.93698 – 0.147186 QB_b1234
Sample Plots Representing Sal Tree Seedlings: n=4					
1	1	1	0.8100	2.9366	Height = 448.1051 – 2.090108 QB_b1
	2	2	0.9442	1.5916	Height = 257.7958 – 0.9060843 QB_b2
	3	3	0.9577	1.3853	Height = 189.7164 – 1.443158 QB_b3
	4	4	0.5412	4.5626	Height = 37.47076 – 0.0463997 QB_b4
2	5	1 2	0.9310	1.7697	Height = 324.6739 – 1.302476 QB_b12
	6	1 3	0.9145	1.9698	Height = 300.7416 – 1.739988 QB_b13
	7	1 4	0.5516	4.5109	Height = 46.70607 – 0.0915296 QB_b14
	8	2 3	0.9536	1.4506	Height = 232.5357 – 1.118192 QB_b23
	9	2 4	0.5721	4.4064	Height = 49.01404 – 0.0900469 QB_b24
	10	3 4	0.5628	4.4539	Height = 42.74973 – 0.0913083 QB_b34
3	11	1 2 3	0.9405	1.6438	Height = 283.05 – 1.347886 QB_b123
	12	1 2 4	0.5811	4.3596	Height = 57.77605 – 0.133144 QB_b124
	13	1 3 4	0.5722	4.4056	Height = 51.73203 – 0.1350091 QB_b134
	14	2 3 4	0.5913	4.3062	Height = 53.86147 – 0.1326834 QB_b234
4	15	1 2 3 4	0.5996	4.2626	Height = 62.36915 – 0.1743245 QB_b1234

** Height is considered as dependent variable.*

Appendix 5

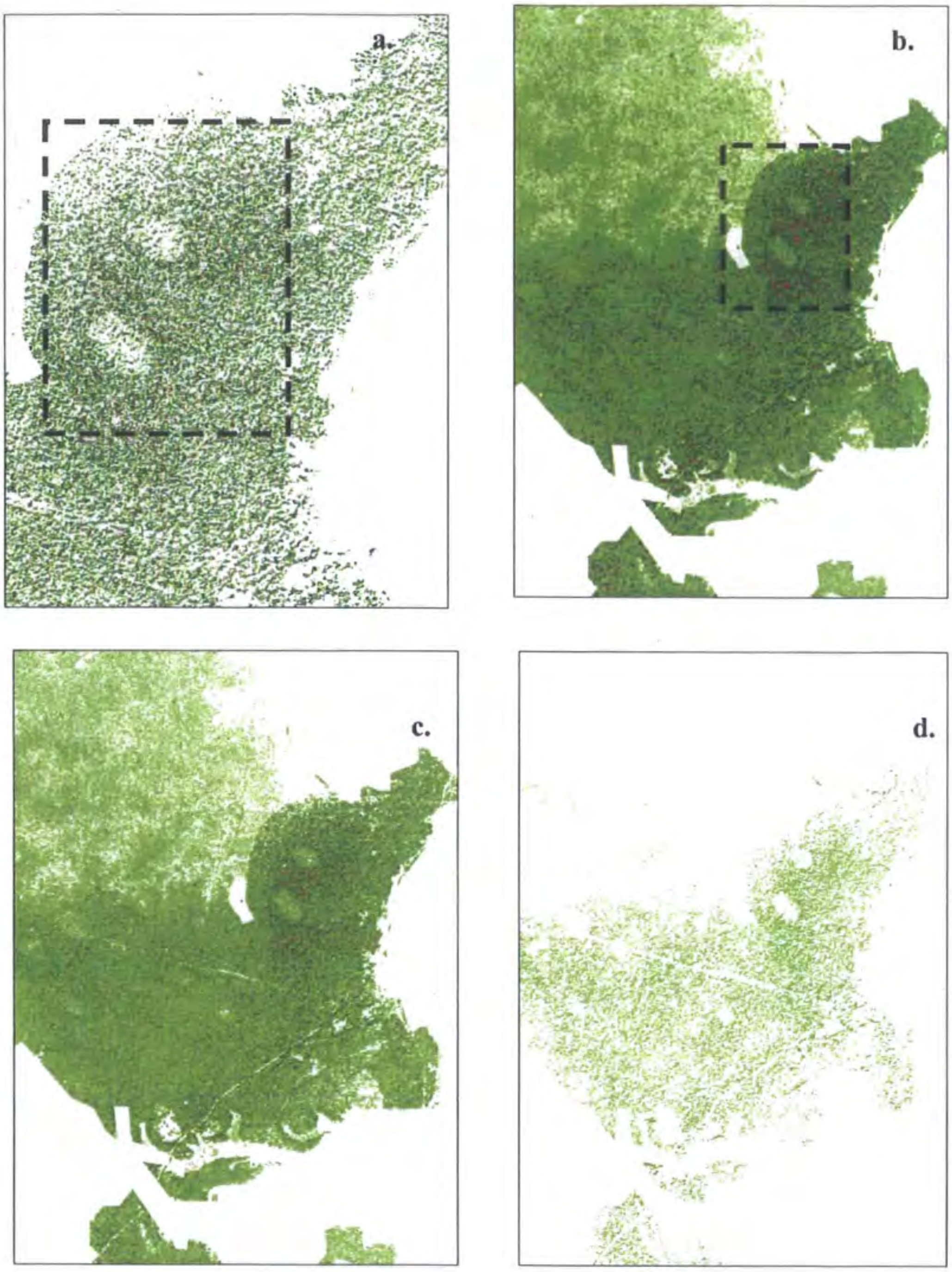


Figure: **a.** Predicted map generated using Quickbird image band 3; **b.** 5 X 5 pixel maximum height value filtered map; **c.** 3 X 3 pixel maximum height value filtered map; **d.** 3 X 3 pixel minimum height value filtered map.

Appendix 6

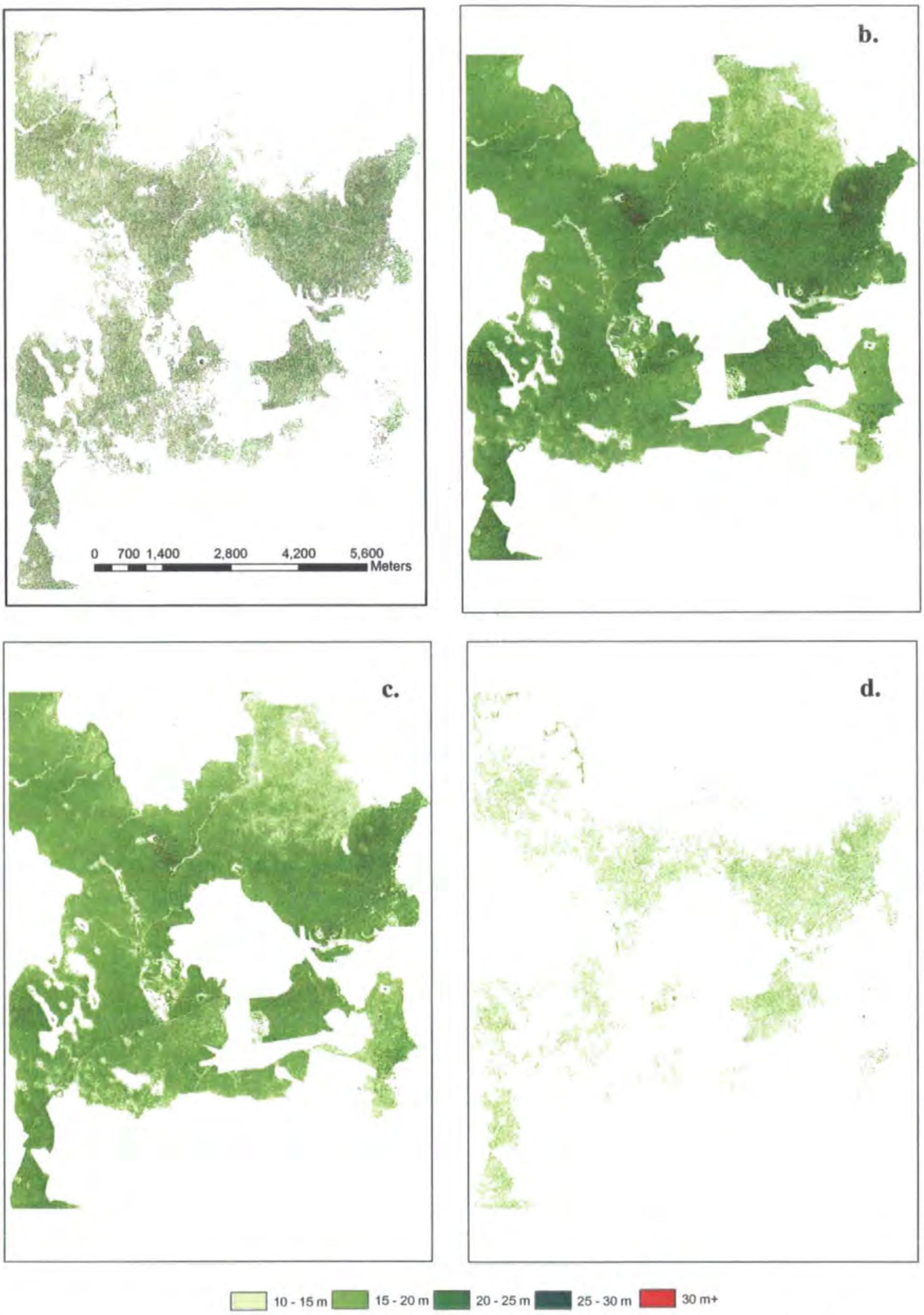


Figure: Addressing the overestimation problem of tree height prediction. a. height map based on original model equation, b. 5 X 5 pixels maximum height value filter map, c. 3 X 3 pixels maximum height value filter map, d. 3 X 3 pixels minimum height value filter map

Appendix 7

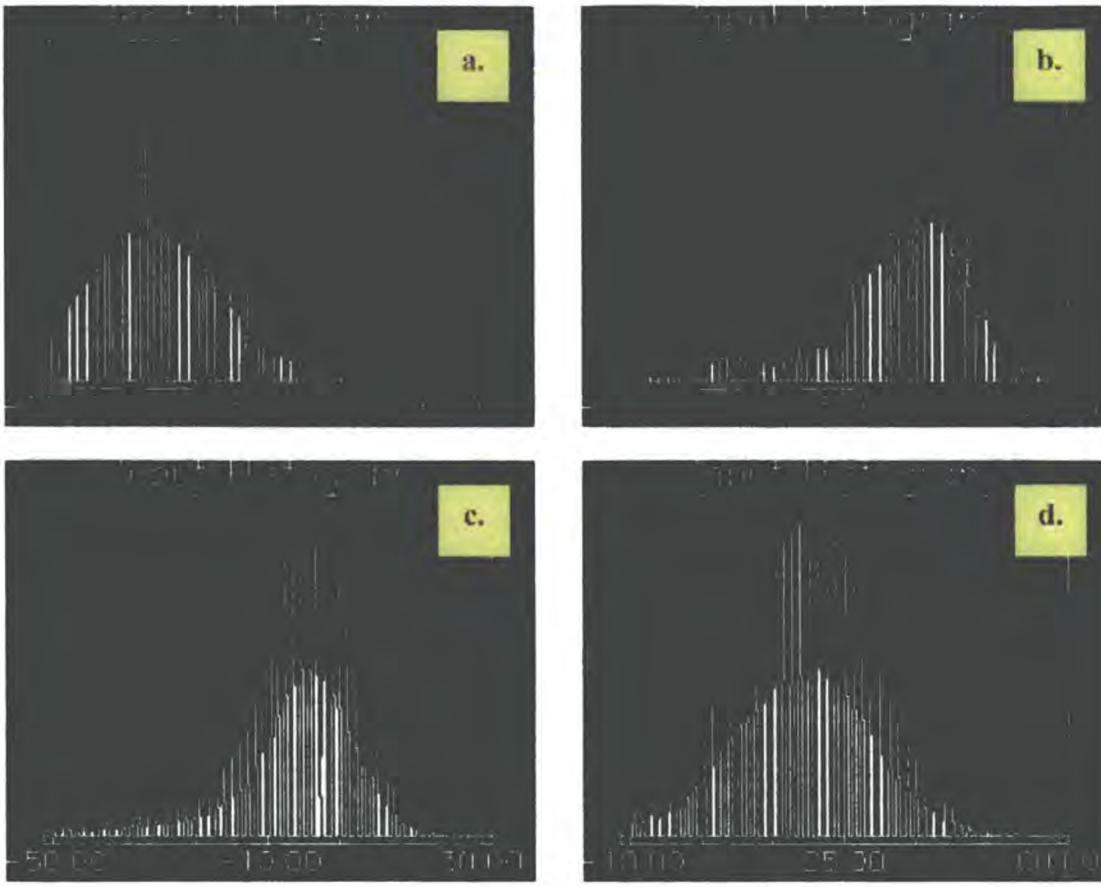


Figure 17: Histogram distribution of a. original model prediction image file, b. 5 X 5 maximum DN value filtering, c. 3 X 3 minimum DN value filtering, d. 3 X 3 maximum DN value filtering.

Appendix 8

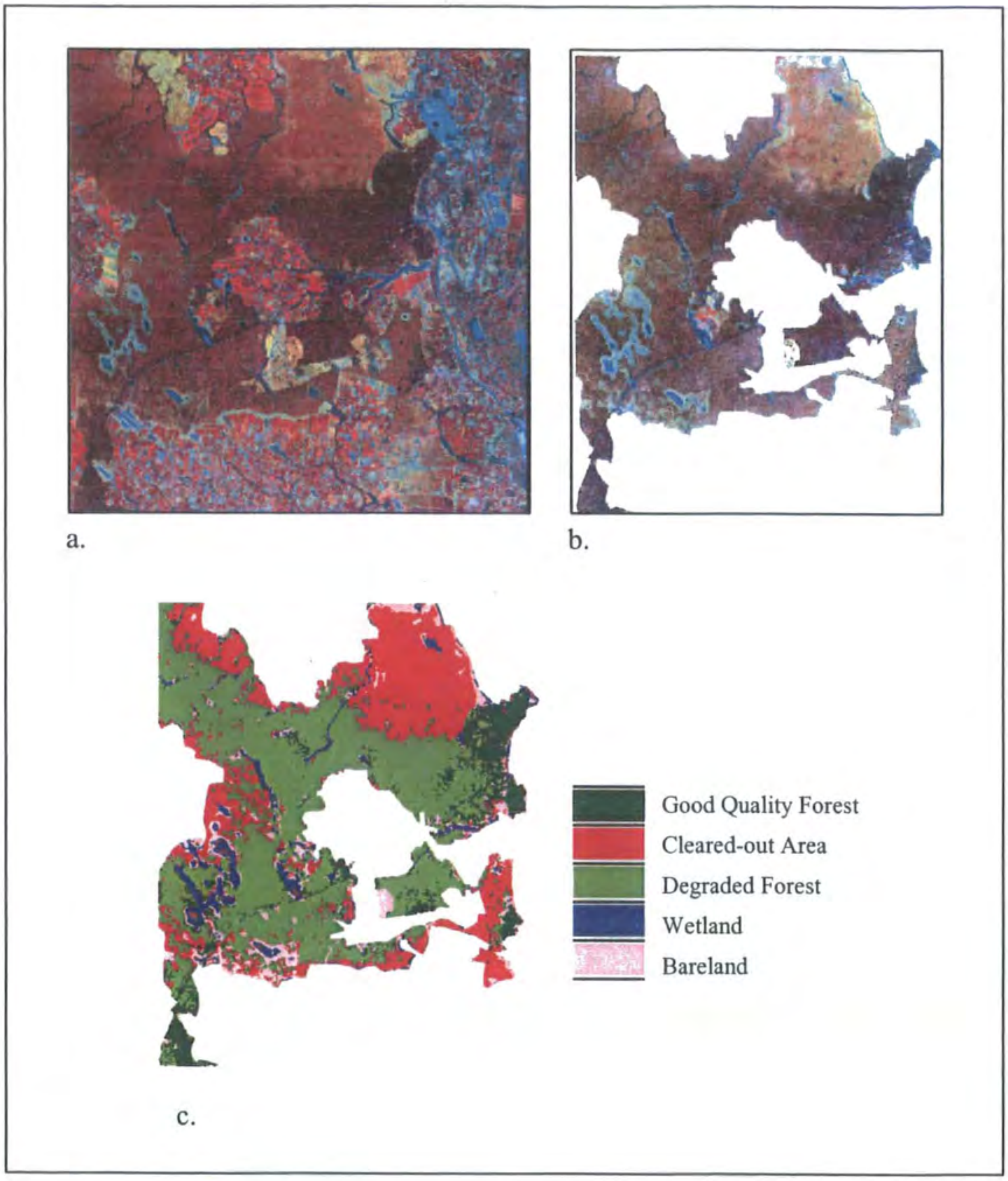
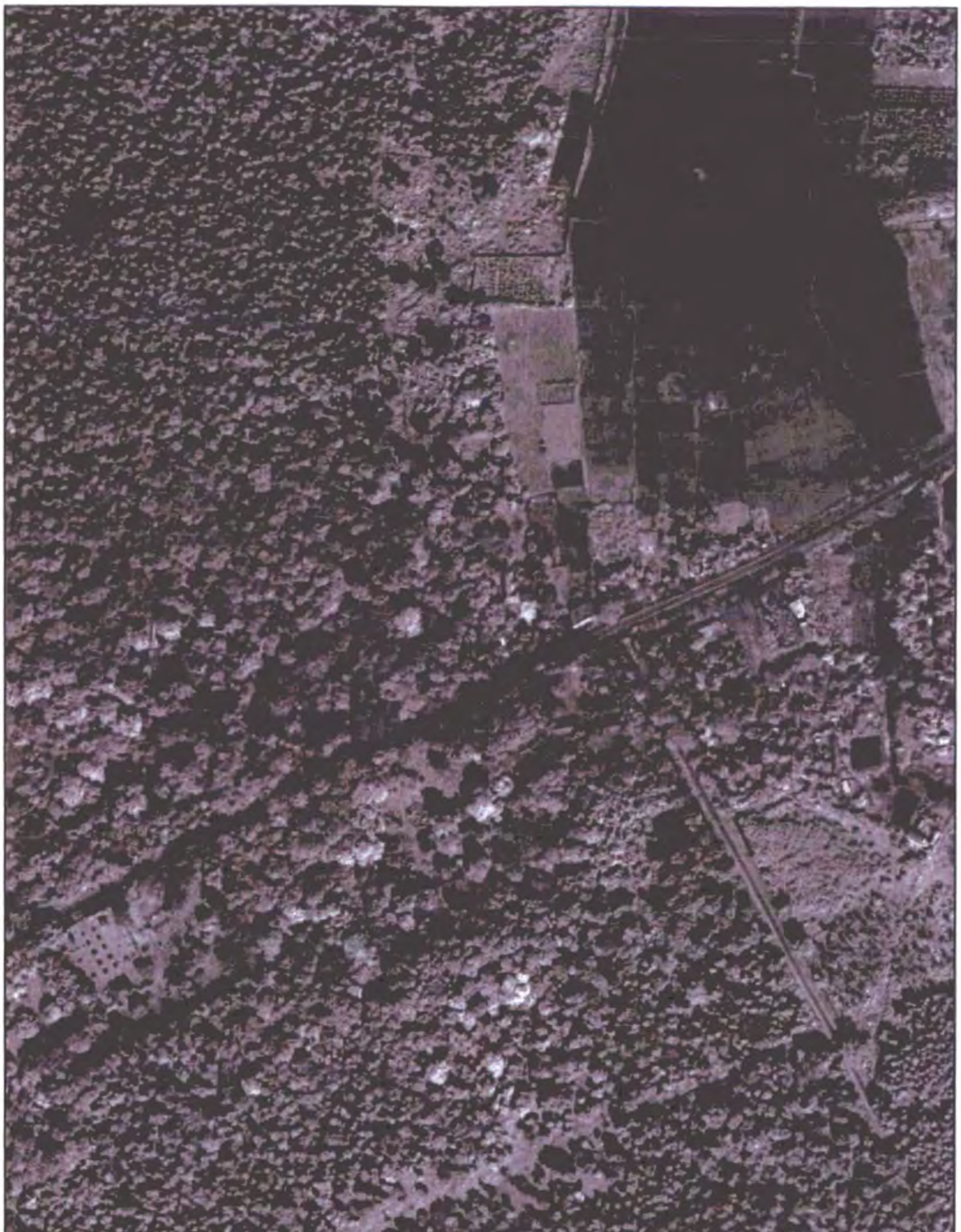


Figure: Comparison of classified map with raw image.

Appendix 9



Appendix 10

Social Forestry Rules

The Forest Department of Bangladesh forwarded a broad sheet proposal on 'social forestry rules' to the ministry of environment and forests with the following inscriptions.

"The draft Social Forestry Rules has been amended to reflected comments received through various consultants, including the last workshop on the 5 December, 2001 and written comments and critics offered by various persons and in particular Raja Debasish Roy and Dr. Sadeqa Halim. Words in bold italics indicate these amendments and footnotes offer brief explanation and/or justification for the amendments. Needless to say, these footnotes are not part of the rules and will be deleted from the final version. The italics underlined portions of the rule indicate the changes made after the workshop of 5 December, 2001."

The draft final proposal is as under

Social Forestry Rules, 2002
Unofficial English version of the Revised Rules

No. S.R.O. In exercise of the powers conferred by sub-sections (4) and (5) of section 28A of the Forest Act, 1927 (XVI of 1927), the Government is pleased to make the following rules, namely:

Short title: These rules may be called the Social Forestry Rules, 2002.
Definitions: In these rules, unless there is anything repugnant in the subject or context –
"Act" means the Forest Act, 1927 (XVI of 1927);
"rotation" means the period described under Rule 7(1);
"beneficiary" means any person who participates in social forestry and is entitled to its benefits under these rules;
"agreement" means an agreement signed between the parties mentioned in rule 3, and includes a memorandum of understanding also;
"Fund" means the Tree Farming Fund constituted under Rule 11;
"Non-Government Organization" means any society formed under the Societies Registration Act, 1860 (Act XXI of 1860) or an organization registered under the Voluntary Social Welfare Organization (Registration and Control) Ordinance, 1961 (Ord. XLVI of 1978) or by the Non-Government Affairs Bureau under the Foreign Donation Voluntary Activities Regulation Ordinance, 1978 (Ord. XLVI of 1978) or a company registered under section 28 of the Companies Act, 1994 (Act 18 of 1994);
"LCO" means Local Community Organization comprised of the beneficiaries involved in social forestry activities in any locality;
"Management Committee" means the Management Committee constituted under Rule 6;
"Fund Management Committee" means the Tree Farming Fund Management Committee constituted under Rule 11(5);
"Social forestry" shall have the same meaning as is assigned to it in sections 28A and 28B of the Act. Further, social forestry under the rule means forestry for the people and by the people. In other words, creation and management of forests with active participation of the people in planning, execution and its conservation to met their own needs and provisions of government.
"Chittagong Hill Tracts Regional Council" and "Hill District Council" shall have the same meaning as in Chittagong Hill Tracts Regional Council Act, 1998;
"Advisors" means advisors under rule 6(3).
"Upazila Chairman" means Upazila Chairman under the Upazila Parisod Act 1998 (Act No. 24 of 1998).

Agreement for social forestry and parties thereto: The following parties, all or any number of them, may enter into an agreement for social forestry in any area, namely:

Forest Department;
Any person or public or statutory body owning or occupying land;
Beneficiaries;
Non-Government Organization
provided that the beneficiaries and the Forest Department shall be parties to any such agreement.
The agreement shall be in such form as may be prescribed by the Government and may be made either separately or jointly.
Where a beneficiary is a married person, both the husband and wife shall be parties to the agreement.
The term of agreement for social forestry shall be –
in the case of a sal forest, twenty years, renewable up to rotation period;
in the case of a natural forest, for twenty years renewable up to rotation period;
in the case of woodlot, agro-forestry, charland plantation, strip plantation, plantation in Barind and any other plantations, for ten years, renewable up to thirty years.

Selection of beneficiaries:
The beneficiaries of social forestry of an area shall be selected by the Forest Department in consultation with the local government organization of that area and the non-government organization associated with the social forestry, if any, of that area.
The beneficiaries shall be selected from amongst the local inhabitants living within one kilometer of the respective plantation site of social forestry and shall preferably be from amongst the following persons, namely:
landless persons;
owners or occupants of less than 50 decimals of land;
destitute women; and
ethnic minority.
Provided that in the event of insufficient number of beneficiaries from within one kilometer of the plantation site, such beneficiaries residing in the nearest areas may be selected.
The selected beneficiaries must be willing to associate themselves with social forestry activities.
In the case of any plantation following the first rotation, beneficiaries shall be selected from amongst current beneficiaries and the persons eligible under sub-rule (2).
The beneficiaries may transfer their duties, functions and benefits under these rules and agreement to their respective wives or husbands or any other legal heir and, in the case of death of a beneficiary, his duties, functions and benefits shall devolve upon a representative of his legal heirs to be nominated by the heirs themselves.

Provided that in the case where duties, functions and benefits of a beneficiary may not be transferred under sub-rule (5) above or legal heirs do not take on the duties, functions and benefits or such beneficiary leaves the social forestry for reasonable cause, the LCO, in consultation with the Forest Department, may assign duties, functions and benefits to another person or persons under sub-rule (2) above and such new beneficiary shall be entitled to profits on a pro-rata basis.

Explanation: If, for example, the initial beneficiary dies after 5 years of his participation in the social forestry activities and his heirs are not willing to continue the duties and functions or the beneficiary has left the locality, the benefits, calculated under Rule 9 below, accruing from felling of trees after 10 years will be divided among the heirs of the dead beneficiary or the erstwhile beneficiary (who has left the social forestry activities) and the substituted beneficiary for 5 years under the preceding proviso in equal proportions.

Selection of non-government organization:
The Government may select one or more non-government organizations for each plantation site under social forestry programme.
In order to be selected under sub-rule (1), a non-government organization should have:

at least two years' experience in group formation, motivation and mobilization work in respect of social forestry or three years experience in development activities; and
its own office at the district or Upazila level.
(3) A non-government organization working in the locality of social forestry concerned and having appropriate technical expertise and trained personnel shall be given preference in selection under sub-rule (1).

Management Committee:
There shall be a Management Committee from each locality of social forestry.
The Management Committee shall be constituted with the following members who shall be elected by the Local Community Organization (LCO) of the locality concerned from amongst them, namely:
one Chairperson
one Vice Chairperson
one General Secretary
one Assistant Secretary
one Treasurer, and
four members
provided that at least one third of them shall be women.
A Forest Officer or a designated government servant of the local Forest Department and one representative of the non-government organization associated with the social forestry concerned, if selected under Rule 5, shall be advisers to the Management Committee.
(4) The members of the Management Committee shall hold office for two years and shall be eligible for re-election:
Provided that any member may resign his post before completion of his tenure of office by a letter addressed to the Chairman.
(5) The Management Committee shall have the following functions, namely:
assisting the Forest Department in social forestry;
proper nursing and maintaining the forest raised under social forestry programme;
motivating the beneficiaries in performing their duties and assisting them in getting their appropriate benefits under these rules;
management and administration of Tree Farming Fund;
dispute resolution and
any other function agreed upon by the management committee.
(6) The Management Committee shall determine its own rules of procedure.
(7) If a dispute between the members of the Management Committee in performing its functions cannot be resolved by the Committee, by a decision of one-third members of the Committee the dispute may be referred to the advisers mentioned in sub-rules (3) for resolution whose decision shall be final and binding.
(8) A Management Committee may be dissolved by the Divisional Forest Officer on the written recommendation of at least one half of the members of the concerned management committee.

Rotation:
The rotation of trees produced under social forestry shall be determined by the Forest Department:
in the case of sal forest, 60 years;
in the case of natural forest, 40 years;
in the case of fruit trees, the period for which such a tree shall bear fruits normally.
No tree shall be felled before its rotation is completed.
Provided that nothing in this rule shall apply in the case of non-timber forest products or felling or uprooting any tree or pruning of branches of any tree required under development activities of the Government or for proper growth and maturity of trees or to remove any sick tree in a social forestry or for any reasonable cause as agreed upon by the Management Committee and the Forest Department.

Duties and functions of parties to the social forestry agreement:

The Forest Department shall have the following duties and functions, namely:
selection of beneficiaries;
making work plan for plantations;
providing technical advice to the beneficiaries for raising social forestry and its management and where necessary, accepting co-operation of any Government or non-government organization in that respect;
making agreement with land owning person or agencies, beneficiaries and non-government organizations and others;
monitoring of social forestry activities and of management of Tree Farming Fund;
training of trainers;
marketing of final harvest and distribution of its income amongst the recipients under rule 9;
where the beneficiaries are unable to produce quality seeds or seedlings, assisting them in getting such seeds or seedlings; and
cutting the branches of trees creating obstacles to the vehicular traffic or any other obstacles;
provided that such duties and functions, particularly those mentioned in sub-rule (b) and (g), will be undertaken by the Forest Department in consultation with the concerned Management Committee.
The landowner or occupier shall have the following duties and functions, namely:
the land under agreement or any interest therein shall not be transferred during the duration of the agreement to the detriment of the agreed social forestry activities;
co-operation in safety, maintenance and management of trees planted in land under agreement; and
not to claim any rent or any money, other than the benefits laid down in Rule 9(2)(c), for the land under agreement.
The beneficiaries shall have the following duties and functions, namely:
a. participate in the development of social forestry management plan;
prepare work plans jointly with the Forest Department;
raising saplings for plantation;
plantation of trees and taking care, maintenance and protection of trees planted;
thinning and pruning of trees as per approved plan;
attending meetings related to social forestry; and
any other activity as per approved plan.
(4) The non-government organization, where involved with social forestry, shall have the following duties and functions, namely:
jointly with the Forest Department, selecting of plantation sites under social forestry programme;
assisting the Forest Department in selecting beneficiaries;
jointly with local Forest Department officials, organizing the beneficiaries in various groups and motivating them in respect of social forestry;
undertaking other social development activities among the organized group of beneficiaries;
provide training to beneficiaries as required by the Forest Department;
maintaining appropriate liaison to ensure benefit sharing agreement to the beneficiaries for effective implementation of social forestry programme;
monitoring supply of quality inputs for the beneficiaries of agro-forestry and wood-lot forestry;
assisting the Forest Department and motivating the beneficiaries in timely plantation and related activities;
providing micro-credit support to the beneficiaries under its own management for income generating and employment activities;
monitoring the share of income receivable by various parties and intermediary benefits derived from pruning, lopping, and thinning of trees and the benefits from the final harvest and assisting the beneficiaries to keep records of all benefits received by them;
providing guidance to the beneficiaries to grow different intermediary crops in different plantation sites and to ensure that the intermediary cropping is compatible with plantation activities;
assisting to resolve at the local level any allegation brought by the Forest Department against any beneficiary;

jointly with the Forest Department and in consultation with the beneficiaries and other members of the community, conducting baseline survey to understand present land use pattern and to identify both detriments and advantages for an appropriate management plan;
assisting the Forest Department in selection and demarcation of appropriate areas for participatory sal forest management and other forestry.

Distribution of income derived from social forestry:
The branches pruned under proviso to rule 7(2), the trees felled during first thinning and the fruits of fruit-bearing trees and non-timber forest products shall be receivable in full by the beneficiaries.
The income derived from trees felled at anytime after the first thinning and after completion of rotation shall be distributed as follows, namely:

in the case of woodlot and agro-forestry in the forest under control of the Forest Department:

(i) Forest Department	45 percent
(ii) Beneficiaries	45 percent
(iii) Tree Farming Fund	10 percent

in the case of sal forest:

(i) Forest Department	65 percent
(ii) Beneficiaries	25 percent
(iii) Tree Farming Fund	10 percent

in the case of strip plantation raised on lands owned or occupied by a person or public or statutory body other than the Forest Department:

(i) Forest Department	10 percent
(ii) The person or body owning or occupying the land	20 percent
(iii) Beneficiaries	55 percent
(iv) Local Union Parishad	5 percent
(v) Tree Farming Fund	10 percent

in the case of plantation in charland and foreshore:

(i) Forest Department	25 percent
(ii) Beneficiaries	45 percent
(iii) Land owner/occupier	20 percent
(iv) Tree Farming Fund	10 percent

rehabilitation and afforestation of gullies, pond and tank boundaries of Barind area:

(i) Forest Department	25 percent
(ii) Beneficiaries	45 percent
(iii) Land owner/occupier	20 percent
(iv) Tree Farming Fund	10 percent

Fees, etc. payable to the non-government organization: Every non-government organization shall, for performing its functions under these rules and providing training to the beneficiaries, be entitled to a fee and training expenditure at such rates as may be prescribed by the Government.

Tree Farming Fund:
There shall be a fund called the Tree Farming Fund for each plantation site under social forestry.
Income derived from the social forestry prescribed under Rule 9 shall be credited to the Fund.
The Fund shall be utilized for all plantations and their nurturing following the first rotation.
After meeting the cost mentioned in sub-rule (3), the balance, if any, may be utilized for forest development activities or providing micro-credit to the beneficiaries for raising plantations, developing private nurseries and for other tree-based activities.

There shall be a Committee called the Tree Farming Fund Management Committee for administration and management of the Fund and it shall be constituted by the following members of the Management Committee, namely:

Vice Chairperson, who shall be the Chairman of the Fund Management Committee;

Assistant General Secretary, who shall be the General Secretary of the Fund Management Committee; and

Treasurer, who shall be the Treasurer of the Fund Management Committee.

The Advisers of the Management Committee shall also be the Advisers of the Fund Management Committee.

All sums credited to the Fund shall be kept in a savings account with any local scheduled bank and the account shall be operated jointly by the General Secretary and the Treasurer of the Fund Management Committee upon a resolution passed by the Fund Management Committee and endorsed by the advisers.

The accounts of the Fund shall be maintained appropriately by the Fund Management Committee and all books, statements and records relating to the account of the Fund shall be kept open for inspection by the beneficiaries and advisers.

Social forestry on private land: Government encourages social forestry on privately owned land, whereby:

Any person may make application to the Forest Department to take up social forestry programme in the land owned or occupied by him.

The Forest Department shall consider all applications received by it under sub-rule (1) and, if approved, may bring the land mentioned in the application under social forestry programme governed by these rules.

In cases of investment by Forest Department on privately owned land, sharing of proceeds of harvesting among the parties will be on the basis of mutual agreement.

In the case of tripartite agreement between the private land owner or occupier, beneficiaries of social forestry, and the Forest Department, the provisions of Rules 8 and 9 in general and 8(2) and 9(2)(c) in particular will apply.

Assignment of rights in reserved forest for social forestry:

A village community to which the rights of Government to or over any land which ahs been constituted a reserved forest is assigned or may be assigned under Section 28 of the Forest Act, 1927 shall be deemed to have been assigned for social forestry and such social forestry may be governed by these rules:

Provided that the beneficiaries of such social forestry in a reserved forest shall have determined by the Forest Department from amongst the villagers to which such rights have been or may be assigned and Rule 4 shall not be applicable for selection of beneficiaries of social forestry on reserved forest;

Provided further that the members of such village shall constitute the Local Community Organization and the Management Committee shall be constituted as under Rule 6(2) and the Forest Department may nominate another three persons from the Local Community Organization as members of such Management Committee;

The beneficiaries and the Forest Department shall perform functions as provided for under Rule 8(1) and (3) as practicable;

The income derived from trees felled at the end of rotation shall be distributed as follows, namely:

(i) Forest Department	65 percent
(ii) Beneficiaries	25 percent
(iii) Tree Farming Fund	10 percent

Application of these rules in the Chittagong Hill Tracts:
In the Chittagong Hill Tracts, the Forest Department shall undertake social forestry in consultation with the Chittagong Hill Tracts Regional Council and the respective Hill District Councils of the three districts of Chittagong Hill Tracts;

There shall be a District Forest Management Committee in each of the three districts of the Chittagong Hill Tracts consisting of the following members:
Chairman of the Hill District Council or his nominee;
1 Member of the Parliament from the concerned hill district or his nominee;
3 Members of the respective Hill District Council to be nominated by the Chairman of the Hill District Council;
2 Forest Officers;
1 female representative of a local non-government organization selected by the District Hill Council;
2 representatives of the civil society selected by the Forest Department, at least one of whom shall be a female.

The criteria for selection of beneficiaries for social forestry in the hill districts shall be determined by the District Forest Management Committee and the District Forest Management Committee shall monitor the selection of beneficiaries by the Forest Department for each social forestry site; and
The benefit sharing formula laid out in Rule 9 shall be modified, with consultation with the Forest Department, by the District Forest Management Committee for social forestry in the respective hill districts for different categories of social forestry.

Dispute Resolution:
Any dispute concerning interpretation or implementation of any agreement for social forestry or condition thereof, including proportion of benefits due shall be resolved conclusively by:
The Management Committee if the dispute is between beneficiaries;
The concerned Forest Officer if the dispute is between the Management Committee and beneficiary;
A Forest Officer superior to the forest official concerned if the dispute is between forest official and the Management Committee or between forest official and beneficiary.
Appeal against any resolution under clause (1) may be preferred to the concerned Upzilla Chairman whose decision shall be final.

National Consultation Forum: (1) The Forest Department, with approval of the Government, shall convene a National Consultation Forum to maintain a policy dialogue and wider participation of civil society in matters pertaining to social forestry.

Application of Transit Rules:
The forest produce from trees commonly found on farms, homesteads, and other small private or community owned properties but not commonly found in natural forest or Government plantations shall be exempt from the application of transit rules.
The Forest Department shall maintain a list of such species exempted from transit rules and shall also review and update such list from time to time.

Appendix 11

Tree volume table for sal (*Shorea robusta*) in the plantations in Bangladesh[1]

INTRODUCTION

Sal (*Shorea robusta* Gaertn. f.) is a medium size tree growing naturally from Tarai in the north to the Maynamoti hills in the south. The species has been planted in the forests of Tangail, Mymensingh, Dinajpur and Sylhet of Bangladesh for its extensive uses. It was also experimentally planted in the forests of Chittagong and Cox's Bazar. The bole of the tree is tall and straight. It attains generally a height of 18 m to 30 m and a diameter of 50 cm to 70 cm (Troup, 1986). The wood is durable and of good quality and hence used extensively for building and construction purposes, railway sleepers, wagons, etc. The older sal plantations are now suitable for felling and to estimate the volume, volume tables are necessary for the species. Therefore, the present volume tables have been prepared for sal growing in the plantations of Bangladesh.

COLLECTION OF DATA

Data were collected from the standing trees of the plantations of 56 - 26 years old for Sylhet and 51 - 11 years old for Tangail and Mymensingh. The plantations were initially raised with a stocking of 2988 seedlings per hectare but at the time of data collection, there were approximately 500 - 1400 trees per hectare. Measurements on diameters at breast height (dbh), total height and diameters at 3.0 meters intervals from the ground level to the top end diameter of 10.0 cm overbark were taken. The bark thickness at each point of diameter measurements was also taken in two perpendicular directions to estimate the diameter under bark. A total of 499 trees were measured for the preparation of volume tables (Table 1). In addition to these, data were collected from a total of 85 trees for validating the selected regression equations.

COMPILATION OF DATA

The volumes of all the sections except the top and bottom portion were computed by using the mean cross-sectional area of the two ends of each section (smallian formula). The bottom section was assumed cylindrical. The top most section was assumed a cone and volume was computed as one third of the cylindrical volume of the portion. The top end diameter measurement for each tree was considered as the base

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[1] See Das *et* al. (1992) in the bibliography list.

diameter of the cone. The volumes of the cone was ignored for estimation of under bark tree volumes. The individual tree volume was then estimated by summing up the volumes of each section of a tree. These individual tree volumes (V) were related to dbh (D) and total height (H) by regression analyses using various functions and transformations as required in the regression models.

COMPUTATION OF VOLUME FUNCTIONS

Multiple regression analyses were done to select the best suited equations. The following 10 equations were tried to select the best fitted one :

1. $V = b0 + b1\ D$
2. $V = b0 + b1\ D + b2\ D^2$
3. $V = b0 + b1\ D^2$
4. $V = b0 + b1\ D^2H$
5. $V = b0 + b1\ D^2 + b2\ H + b3\ D^2H$
6. $V = b0 + b1\ D^2 + b2\ DH + b3\ D^2H$
7. $\log_e(V) = b0 + b1 \log_e(D)$
8. $\log_e(V) = b0 + b1 \log_e(D) + b2 \log_e(H)$
9. $V/D^2 = b0 + b1\ HD^2 + b2\ /H + b3/D^2$
10. $V/D^2 = b0 + b1\ /D^2 + b2/H + b3/D$

where, V, D and H are described as above, b0 is the regression constant and bi's are regression coefficients. The logarithmic functions are to the base e.

The regression model of best fit were chosen based on small furnival index, high multiple coefficient of determination, low mean sum of error squares and high F-Value.

Models were selected for estimation of total volume over bark and total volume under bark to a top end diameter of approximately 9.0 cm under bark. The selected equations were transformed for estimation of volume from girth at breast height (G). The equations were also converted for imperial units.

VALIDATION TEST PROCEDURE

The best suited regression equations were tested with a set of independent data on 85 trees collected and compiled in the same procedure. The actual volumes of these trees were collectively compared with the corresponding volumes predicted by the selected models. The independent tests for validation criteria were :

i) The paired t - test (Dawkins, 1975) :

$$t = \frac{d}{S.E.\ (d)}$$

with (n - 1) df at 0.05 level

where, d = Average of the difference of the pairs of the actual and the estimated volumes.

S.E. (d) = Standard error of the average difference

n = Number of pairs.

The criterion of insignificant difference has been followed.

ii) Regression analysis (Cox 1984) :

a) $A - E = b_0 + b_1\ E$

b) $A - E = b_0 + b_1 E + b_2 E^2$

Where, A and E indicate the actual and the estimated volumes respectively.

The criterion of significant for F and t have been followed.

iii) Absolute per cent deviation (% AD) :

$$\% \text{ AD} = \frac{|\Sigma (A - E)|}{\Sigma A} \times 100$$

Where, A and E are the actual and the estimated total volumes respectively.

A % AD of less than 10 per cent of absolute deviation has been considered as a selection criteria.

iv) (A - E) vs E plot

Where, A = Actual volume
E = Estimated volume

Criterion : If the plot indicates horizontal band the model is adequate

v) A vs E plot & regression

Criterion . The nearer the slope to 45 is the better

RESULTS AND DISCUSSIONS

The equations for total volume overbark and total volume underbark to a top end diameter of 9.0 cm underbark were selected. The mean sum of squares (MSE), coefficient of determination (R^2), F - value, and the Furnival Index (FI) of the selected equations are given in table 2

The best selected and trans-formed/converted equations are given below

METRIC UNITS

Total volume overbark (V_{mo}) for one way

$$\log_e(V_{mo}) = -9.1727759 + 2.5178944 \log_e(D)$$

$$\log_e(V_{mo}) = -12.0554 + 2.5178944 \log_e(G)$$

Total volume underbark to a top end diameter of approximately 9.0 cm under-bark (V_{mu}) for one way .

$$V_{mu} = -0.1011481 + 0.0006209\ D^2$$
$$V_{mu} = -0.1011481 + 0.0000629\ G^2$$

Total volume overbark for two way

$$\log_e(Vmo) = -9.615639 + 2.033071 \log_e(D) + 0.7361229 \log_e(H)$$

$$\log_e(Vmo) = -11.938881 + 2.033071 \log_e(G) + 0.7361229 \log_e(H)$$

Total volume underbark to a top end diameter of approximately 9.0 cm under bark (V_{mu}) for two way

$$V_{mu} = 0.0032556 + 0.0000369\ D^2H$$
$$V_{mu} = 0.003255 + 0.000002755\ G^2H$$

IMPERIAL UNITS

Total volume overbark (V_{io}) for one way

$$\log_e(V_{io}) = -3.2615386 + 2.5178944 \log_e(D)$$
$$\log_e(V_{io}) = -6.1438476 + 2.5178944 \log_e(G)$$

Total volume underbark to a top end diameter of approximately 3.5 inches underbark (V_{iu}) for one way :

$$V_{iu} = -3.5720185 + 0.14146622\ D^2$$
$$V_{iu} = -3.5720185 + 0.0143335\ G^2$$

Total volume overbark (V_{io}) two way :

$$\log_e(V_{io}) = -5.02669 + 2.033071 \log_e(D) + 0.7361229 \log_e(H)$$

$$\log_e(V_{io}) = -7.3540131 + 2.033071 \log_e(G) + 0.7361229 \log_e(H)$$

Total volume underbark to a top end diameter of 3.5 inches underbark (V_{iu}) for two way :

$$V_{iu} = -0.11496 + 0.001867 D^2H$$

$$V_{iu} = -0.11496 + 0.0001894 G^2H$$

where, m = metric units

i = imperial units

u = underbark

o = overbark

D = Dbh

G = Girth at breast height

H = total height

Validation of the Selected Models : The test statistics are presented in the table 3. The selected models satisfied all the criteria. The most vivid ones are the slopes and per cent total deviations. They are nearly 45 degree and less than 5% respectively. This nature was considered sufficient to mark the importance of little discrepancies in the horizontal bands of deviations. From the results of the validation of the models, it can be concluded that the selected models can be safely used for estimation of the volumes of the sal tree in the plantations of Bangladesh

After the validation test, volume tables were prepared for ready use and are presented in Appendices I to VI.

CONFIDENCE LIMIT

These volume tables should not be used to determine volume of individual tree in a stand. These tables may be used for the mean tree of a stand which may be multiplied by the number of stem to get the volume. Estimation of volumes for trees much out side the height and dbh ranges shown in the stand table should only be done with caution.

ACKNOWLEDGEMENT

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Table -1. Sal *(Shorea robusta)* in plantations of Bangladesh, diameter at breast height and height class distribution of sample trees.

DBH (cm)	Height in meters 5	8	11	14	17	20	23	26	29	Total
10	15	31	29	8	-	-	-	-	-	83
15	1	31	43	23	4	1	-	-	-	103
20	1	14	18	35	26	3	-	-	-	97
25	-	-	7	23	27	8	2	-	-	67
30	-	-	1	9	19	16	-	-	-	45
35	-	-	-	6	16	17	10	-	1	50
40	-	-	-	-	7	5	6	3	-	21
45	-	-	-	-	1	11	3	3	1	19
50	-	-	-	-	3	5	1	1	-	10
55	-	-	-	-	1	2	-	-	-	3
60	-	-	-	-	1	-	-	-	-	1
TOTAL	17	76	98	104	105	68	22	7	2	499

Table 2. Sal *(Shorea robusta)* in plantation of Bangladesh, results of regression analyses of the relating volume with height and/or dbh.

EQUATIONS	MSE	R squared	F	F I.
1. $\log_e(V_{mo}) = b0 + b1 \cdot \log_e(D)$	0 03856	9666	14383 46	0 0575
2. $\log_e(V_{mo}) = a + b \cdot \log_e(D) + c \cdot \log_e(H)$	0.01696	.9853	16669 57	0 0381
3. $V_{mu} = b0 + b1 \cdot D^2$	0 00776	9551	10568 40	0.0881
4 $V_{mu} = b0 + b1 \cdot D^2 \cdot H$	0.00652	9622	12666 66	0 0808

Table 3. Validation test statistics of the selected models for estimation of volume for sal in the plantations of Bangladesh

EQUATIONS	PAIRED t	%AD	A-E=b0+b1E F	A-E=b0+b1E t	A-E=b0+b1E+b2E^2 F	A-E=b0+b1E+b2E^2 t		Slope E vs A
				b1		b1	b2	deg.
Equ. 1	1.514	3.9	51.16	0.0098	26.63	0.0617	0.0405	45.6
Equ. 2	0.037	0.1	27.45	0.0131	19.25	0.0518	0.0348	46.3
Equ. 3	1.904	4.1	28.07	0.0091	3.92	0.0489	0.0355	45.61
Equ. 4	0.204	0.5	31.23	0.0081	4.65	0.0569	0.0403	45.44

Appendix I. **Sal *(Shorea robusta)* in the plantations of Bangladesh, total volume overbark (Vmo) and total volume underbark to a top and diameter o· approximately 9.0 cm (Vmu) in cubic meters for dbh and girth in centimeters.**

Dbh (cm)	Vmo	Vmu	Girth (cm)	Vmo	Vmu
6	0.009		20	0.011	
8	0.020		26	0.021	
10	0.034		32	0 036	
12	0 045		38	0.055	
14	0.080	0.021	44	0.080	0 021
16	0.112	0.058	50	0.110	0.056
18	0.150	0.100	56	0.147	0.096
20	0 196	0.147	62	0.190	0 141
22	0.249	0.199	68	0.239	0.190
24	0.310	0.257	74	0 296	0.244
26	0.379	0.319	80	0.360	0.302
28	0.457	0.386	86	0.432	0.365
30	0.544	0.458	92	0.512	0.432
32	0 640	0 535	09	0 600	0 504
34	0.746	0 617	104	0.697	0 580
36	0 861	0 704	110	[illegible]	0 661
38	0.987	0 795	116	0 918	0 747
40	1.123	0.892	122	1.042	0 837
42	1.269	0 994	128	1 176	0 931
44	1 427	1.101	134	1.320	1 030
46	1 596	1.213	140	1.474	1 334
48	1.777	1.329	146	1.638	1 242
50	1.969	1.451	152	1.813	1 354
52	2 173	1.578	158	1 998	1 472
54	2.390	1.709	164	2.195	1 593
56	2.619	1.846	170	2 403	1 720
58	2 861	1.988	176	2 622	1 850
60	3.116	2.134	182	2.853	1 986
62	3.384	2.286	188	3.096	2 126
64	3.666	2.442	194	3.350	2 270
66	3.961	2.604	200	3.617	2.419
68	4.270	2.770	206	3.897	2.572
70	4.594	2 941	212	4.189	2 730
72	4.932	3.118	218	4.494	2 893
74	5.284	3 299	224	4.812	3.060
76	5 651	3 485	230	5.143	3 232
78	6 033	3 676	236	5 488	3 408
80	6.430	3 873	242	5 846	3 588

Appendix 12

Figure a: Closed canopy forest in Madhupur. Source: Author

Figure b: Open canopy forest in Madhupur. Source: Author